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CONTRIBUTION TO THE KNOWLEDGE OF *Rzehakina* Cushman (FORAMINIFERA) IN NEW ZEALAND

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(With an Appendix on Statistical Method applied to Bi-variate Analysis of *Rzehakina* Cushman by Miss M. T. K. CHUNG, and R. M. WILLIAMS, Applied Mathematics Laboratory, Wellington)

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Abstract

Rzehakina Cushman first appears in the lower Raukumara Series (lower Senonian) becoming widespread and abundant in the Haumurian and Teurian prior to its extinction in lower Dannevirke time (Paleocene). The problem of variability within the genus has been approached by analysing samples in terms of prolocular size, gross dimensions and coiling. Distinction of generational forms is basic to this approach. Early Haumurian samples contain two generations separable only upon their prolocular dimensions. Later Haumurian and Teurian samples reveal progressive attenuation in the shape of the microspheric generation together with rotation of planes of coiling of early chambers. The megalospheric generation throughout maintains stability in shape dimensions. A third form, considered a further microspheric generation but exhibiting morphological stability, ranges from upper Haumurian into Teurian strata. All forms are referred to *Rzehakina epigona* (Rzehak) pending closer investigation of this species.

INTRODUCTION

Variability of morphological characters at the infra-population level within groups of smaller Foraminifera has long been a cause of difficulty to the taxonomist. Miller's early strictures (quoted by Heron-Allen, 1894), "In preparing your slides you should be very careful to select typical specimens only, the intermediate things are a nuisance and should be severely ignored, unless the types are absent from the deposit . . ." are now commonly held up for ridicule (Newell, 1947). Much current practice, however, appears to

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have little to recommend it. With the newly arisen interest in the taxonomy of the Globotruncanidae and Globigerinidae a spate of new taxonomic divisions has appeared; usually these are extremely finely drawn and based solely upon subjective decisions. Often no clear attempt is made to estimate variability and in fact one may wonder whether or not there has been a return to the archetypal concept of the last century. In other groups similar situations obtain: how often does one read in the proposal of a new taxonomic unit any recognition of the fact of alternation of generations and its morphological consequences. The number of instances in which generational forms of the one species have been granted full specific status are no doubt legion.

In the group here considered, *Rzehakina* Cushman, variability has been commented upon by most authors who have dealt with the genus (Finlay, 1939; Thalmann, 1949). Nevertheless little attempt has been made to rationalise such variability. Finlay (1939, p. 535) discussing this problem in New Zealand representatives of the genus noted that " . . .such enormous variation is obvious at any one locality yielding a large enough suite that no good purpose is seen here at present in separating any variation from *epigona*", and further that " . . . variation does not seem to have any stratigraphic use and occurs at all horizons . . .". Thalmann (1949) in his excellent review of the genus tends to adopt a similar view. In fact the only attempts so far made to grapple with the problem have been by Cushman and Jarvis (1928) with the proposal of *Rzehakina epigona* (Rzehak) var. *lata* and by Cushman and Renz (1946) in setting up *Rzehakina epigona* (Rzehak) var. *minima*. However, according to Dr H. M. Bolli (pers. comm.), a wide range of intermediate forms is to be found in the Caribbean region linking these two varieties.

Yet despite the complexity of its morphological variation, *Rzehakina* through its wide geographic occurrence and limited stratigraphic range in the New Zealand Upper Cretaceous and Paleocene is clearly an important guide fossil often of great value to the stratigrapher (Wellman, 1955). Moreover, as emphasised by Finlay (1939) and Thalmann (1949), it appears to have considerable potential as an element in world correlation.

The essential purposes of this paper are to record some aspects of the morphological variability of local populations of *Rzehakina* and to examine the possibility of this variability having a stratigraphic interpretation.

CRITERIA APPLIED IN MORPHOLOGICAL ANALYSIS

The results of modern study of the life history of the Foraminifera (Le Calvez, 1938, 1953; Myers, 1935) show that study of variation within populations must proceed at two levels: at the primary level different generations must be sought for and clearly separated into homologous groups to which, at the secondary level, can be applied techniques capable of estimating the nature of morphological variability of characters of taxonomic value. In the present study distinction between generations has been based primarily upon the size of proloculi, a character readily measurable in a genus such as *Rzehakina* which tends to planispiral coiling. In certain cases, however, where chamber arrangement prohibited direct measurement of the proloculus, the pattern of coiling has been used to separate groups.

Selection of characters capable of suitably measuring variability within homologous groups has been limited to those most readily measurable whilst at the same time being of use in the analysis of relative growth. Features of the aperture were ruled out primarily because this structure is often damaged in fossils. Likewise characters relating to morphology of chambers have not been greatly used in this study because of the need for sectioning in the specimens where heavy callus development nullified the use of the oil immersion method. In a morphologically simple genus such as *Rzehakina* these considerations left only the possibility of the gross dimensions – length, width and thickness. Although thickness may in fact be a suitable character, it presents mensuration problems in that position of measurement of maximum thickness must vary according to the state of the callus development. Characteristically this is limited to two knobs around the site of the penultimate and antepenultimate chamber junctions (Fig. 13), yet in some samples a wide thick callus sheet tends to spread from these knobs over the whole surface causing a median displacement of the position of maximum thickness. Moreover, it seems probable that such callus development may be phenotypically controlled if it is valid to draw a comparison with the results obtained by Heron-Allen (1915) from his experiments in cultivating *Massilina secans* (d'Orbigny) in a medium containing varying amounts of calcium carbonate. Length and width alone have therefore been used: much of the apparent variation within the genus can be analysed in terms of these two characters, which are easily measurable, only moderately subject to distortion due to diagenetic factors and eminently suited to studies of relative growth in that they are both directly controlled by the chamber plan of the individual. It is notable that Pazdrowa (1958), studying an isomorphic genus, *Opthalmidium,* based her biometric study upon the same two dimensions.

BIOMETRICAL CHARACTERISATION

A simple form of bivariate analysis using the reduced major axis technique of Kermack and Haldane (1950) has been applied throughout. Lines have been fitted according to:

$$y = \frac{S_y}{S_x} x + \left(\bar{y} - \frac{S_y}{S_x} \bar{x} \right) \qquad \text{……………………………………………}(1)$$

which may also be stated as

$$\frac{y - \bar{y}}{S_y} = \frac{x - \bar{x}}{S_x} \qquad \text{……………………………………………}(2)$$

where s is the standard deviation, $\bar{x}$ and $\bar{y}$ mean values for the variates x and y and $\frac{S_y}{S_x}$ the growth ratio. Data in original form have been used as a "goodness-of-fit" test applied to an isometric line shows it to be adequate (Table 2). Olson and Miller (1951) have recorded that in paleontological studies involving relative growth, an isometric relation has usually been found adequate.

Tests of significance between pairs of growth ratios (a) have been made according to

$$z = \frac{a_1 - a_2}{({}^{\sigma}a_1{}^2 + {}^{\sigma}a_2{}^2)}^{\frac{1}{2}} \quad \text{..........} \quad (3)$$

where σa is the standard error of the growth ratio. Imbrie (1956) and Kermack (1954) suggest testing for identity of position of reduced major axes according to

$$z = \frac{x_0\,(a_1 - a_2) + (b_1 - b_2)}{[\,({}^{\sigma}a_1{}^2)\,(x_0 - \bar{x}_1)^2 + ({}^{\sigma}a_2{}^2)\,(x_0 - \bar{x}_2)^2\,]^{\frac{1}{2}}} \quad \text{..........} \quad (4)$$

It can be seen that the value of z obtained from this formula is very sensitive to the value of x_0 chosen and that the denominator becomes very small when $\bar{x}_1$ is close to $\bar{x}_2$ and x_0 is chosen close to them (see appendix). For this reason Kermack's formula has been abandoned and discriminant functions (Rao, 1952) computed to test for differences in sample positions.

Bias in the samples due to selection in sorting, and selective damage of specimens due to diagenetic factors and washing of the samples, has not been estimated. Samples were originally washed over a 200-mesh sieve and later dry-sieved into three size grades for sorting. Most samples were sorted exhaustively.

Rzehakina IN THE EASTERN BASIN

The approach adopted in this and the succeeding section is to chart the stratigraphic distribution of *Rzehakina* within two local provinces of late Cretaceous-Paleocene sedimentation, the Eastern Basin (Kingma, 1959) and Northland, and to illustrate the range of morphological variability by detailed study of selected faunas.

(1) Rzehakina *in the Raukumara Series*

Knowledge of *Rzehakina* in rocks of Raukumara age in the Eastern Basin is based primarily upon the sequence occurring in Puketoro Stream (Poverty Bay). Here the lowest sample containing a microfauna (N80/513, F9487) in the section collected by Dr H. W. Wellman in 1954 contains tiny, poorly preserved specimens referable to the genus. This sample, associated with *Inoceramus rangatira* Wellman, an Arowhanan index (Wellman, 1959), was taken from an horizon 700 ft above the apparent unconformity at the base of the Raukumara sequence. The succeeding sample (N80/515, F9488) contains similar specimens while larger examples, still very rare, occur in sample N80/517, (F9490), 1,800 ft above the apparent unconformity. On the basis of Inocerami, this horizon is dated as Teratan. The series of samples collected through the same section by the New Zealand Petroleum Co. and now lodged in the New Zealand Geological Survey reveals a similar pattern, with rare specimens of *Rzehakina* occurring through the Raukumara. Above the Teratan horizon the section is subject to structural complication and it appears that the lower portion of the Mata Series is missing (Mr M. C. Pick, pers. comm.).

(2) *Samples of Haumurian age*

Attention may firstly be drawn to a series of samples containing material adequate for biometric study, taken from the Tapuwaeroa Group (Fleming and Wellman, in Fleming (Edit.), 1959, p. 378) at the exposure along Tangaruhe Stream in Dannevirke Subdivision (Lillie, 1953). The two lower samples, N150/548 (F13628) and N150/547 (F13627) from the western flank of the Whangai anticline are from dark siltstones and sandstones underlying Whangai Argillite. Almost all specimens of *Rzehakina* in both samples, although fairly well preserved, show damage to the proloculus, the five measurable proloculi ranging from 29 to 38 μ in diameter. Division of the sample into generational groups being thus impossible, reduced major axes have been fitted to the total samples. Judged from the evidence of the succeeding sample HT 58B (F8633), little error is incurred by this procedure. The two samples, as defined in terms of regression statistics, are closely allied (Figs. 1, 2). In these and in succeeding figures the following symbolism is used:

n = number of specimens in sample;
$\bar{x}$ = sample mean for variate x, width;
$\bar{y}$ = sample mean for variate y, length;
S_x = standard deviation of x;
S_y = standard deviation of y;
r = coefficient of correlation;
a = growth ratio $(a = \frac{S_y}{S_x})$;
σ_a = standard error of a;
b = initial growth index $(b = \bar{y} - \frac{S_y}{S_x}\bar{x})$.

The growth ratio (a) for the stratigraphically lower sample F13628 is 1·317 ($\sigma_a = 0·135$) and that for F13627 is 1·505 ($\sigma_a = 0·156$). However, this difference appears not to be significant ($z = 0·91$). Similarly, discriminant analysis fails to show any significant difference in the position, i.e., lateral displacement, of the reduced major axes. The amount of relative variation in shape proportionate to the average shape of the sample as estimated by the coefficient of relative dispersion about the reduced major axis (Dd of Imbrie, 1956) is 10·84 in N150/547, and 9·97 in N150/548. These values are higher than those encountered in younger samples in Tangaruhe Stream; this may well be due to the pooling of more than one generational group in calculating the sample statistics.

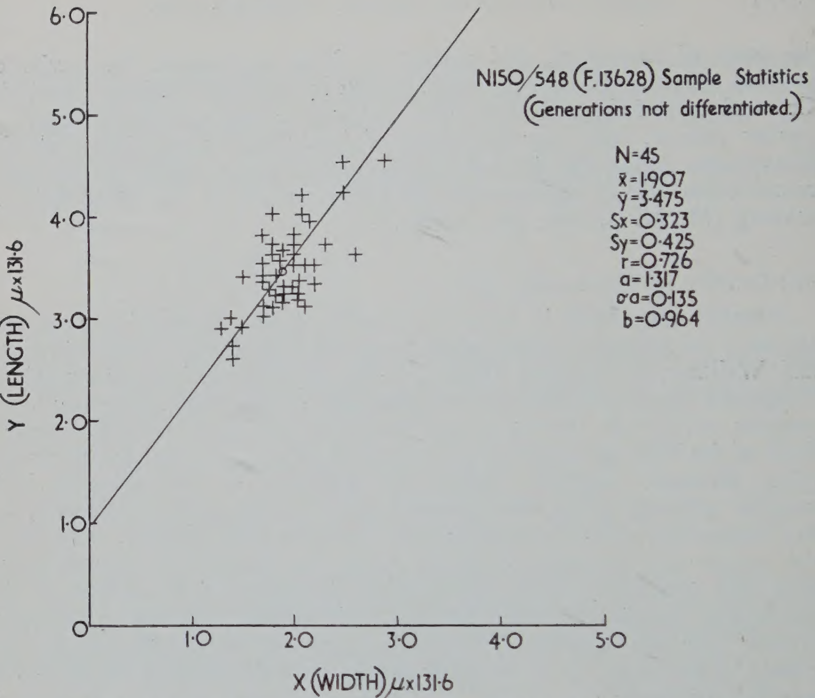


FIG. 1—Relation between Length and Width, N150/548, with plotted reduced major axis and sample statistics.

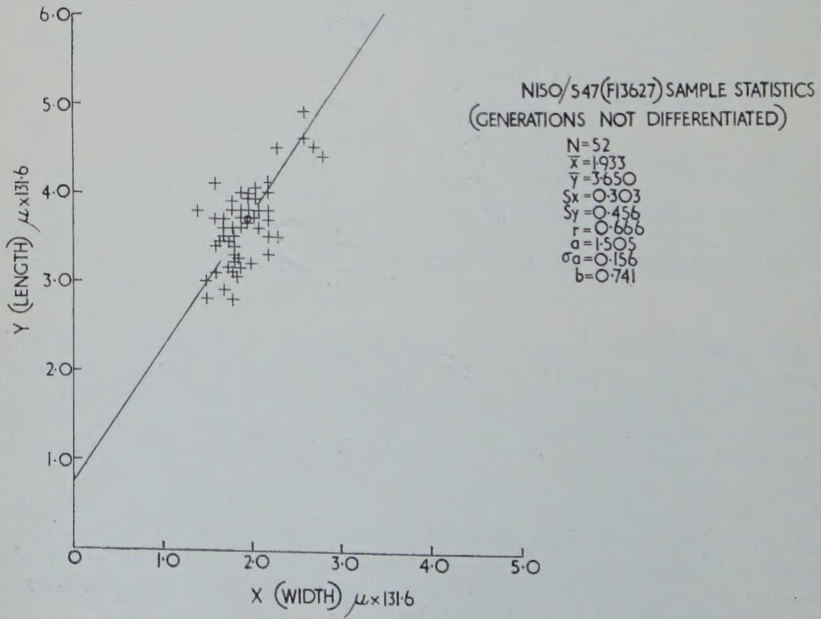


FIG. 2—Relation between Length and Width, N150/547, with plotted reduced major axis and sample statistics.

The next sample from Tangaruhe Stream – HT 58B(F8633) – is an Oil Company collection from the base of the Tapuwaeroa rocks exposed on the eastern flank of the anticline. It should be pointed out at this stage that the interpretation of the sequence in Tangaruhe Stream made by Lillie (1953, Figs. 3 and 6) requires revision in that his Raukumara Formation is in fact of Clarence age, the Tapuwaeroa Group being in fault contact with it, probably on both flanks of the anticline (Dr J. T. Kingma, pers. comm.). There is at present no definite evidence of the presence of strata belonging

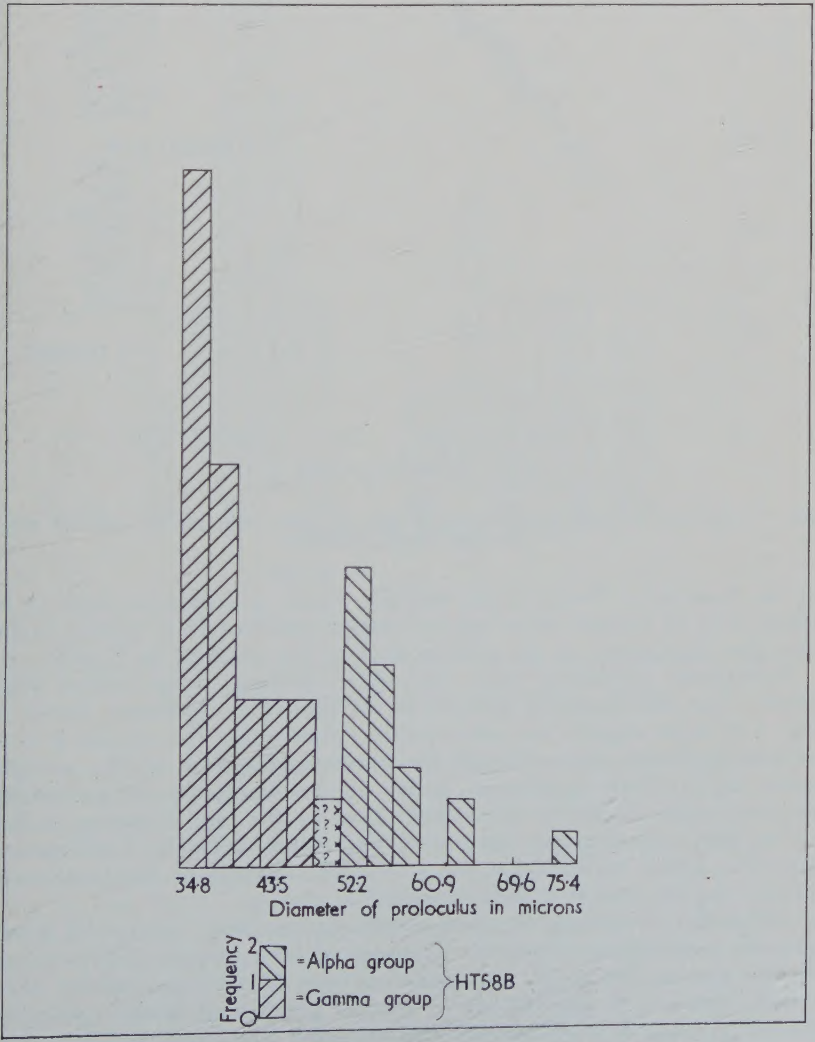


FIG. 3—Distribution of prolocular diameters, HT58B.

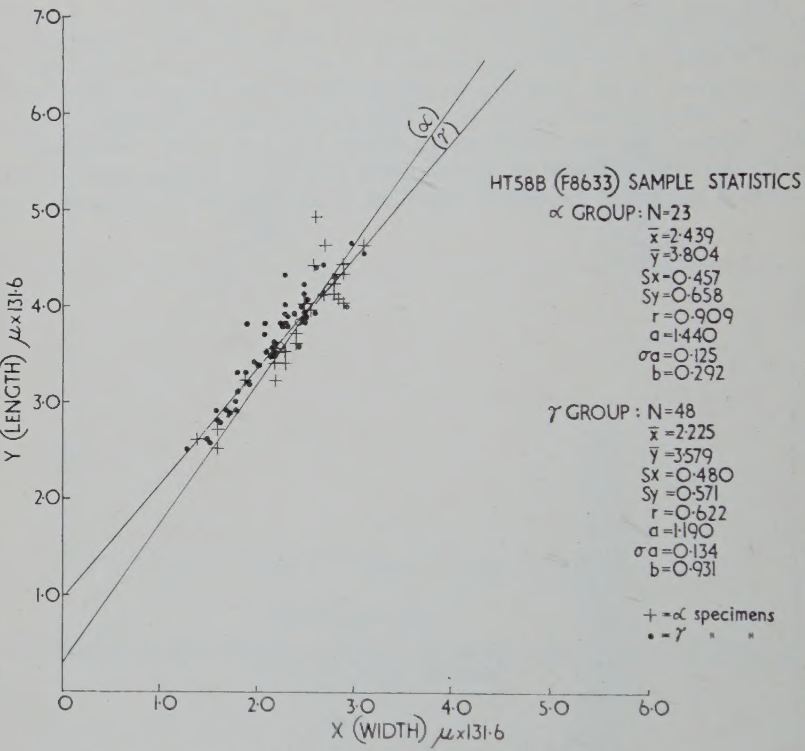


FIG. 4—Relation between Length and Width, HT58B, with plotted reduced major axes and sample statistics.

to the Raukumara Series in this section. F8633 is considered here to be taken from an horizon either approximately equivalent to or slightly higher than that represented on the western flank of the structure by F13627.

Seventy-one individuals with measurable proloculi were studied from F8633. The size-frequency distribution of prolocular diameters, shown in Fig. 3 strongly suggests that dimorphism occurs within the sample. It is of interest to observe that although the lower maximum is at 35 μ and the upper at 52 μ there appears to be no distinct segregation of generations such as Cosijn (1938, p. 48) insisted must be the case. However Hofker (1950, Fig. 214) illustrates the case of *Ceratobulimina pacifica* Cushman and Harris in which he finds that the prolocular diameters of his three generations – A_1, A_2, and B – show considerable overlap.

Although, considering this sample in isolation, there is no valid reason why the nomenclature of Munier-Chalmas and Schlumberger (1883) should not be applied, the group with proloculi from 50 to 75 μ diameter being called "form A or megalospheric" and the group with smaller prolocular diameters "form B or microspheric", this course is not followed because of complications found in younger samples bearing *Rzehakina*. To main-

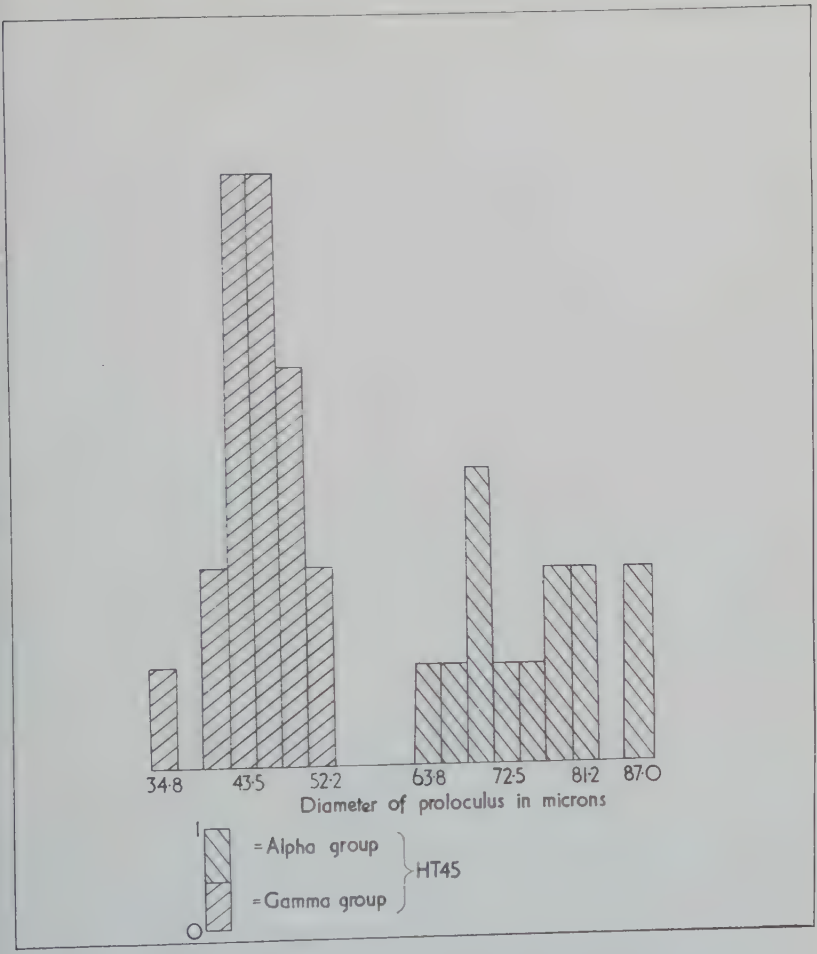


FIG. 5—Distribution of prolocular diameters, HT45.

tain an objective nomenclature throughout this study, the specimens in F8633 with prolocular diameters within the range 50–75 μ are called the α group (Figs. 10, 11, 13) and those with diameters under 50 microns the γ group (Figs. 12, 15). Both groups when observed in glycerine show simple planispiral coiling. Values for a, growth ratio (Fig. 4), are 1·440 ($\sigma_a = 0{\cdot}125$) for the α group and 1·190 ($\sigma_a = 0{\cdot}134$) for the γ group. However this difference in values of a is not significant ($z = 1{\cdot}37$). The two groups, therefore, as estimated by this sample can only be separated by prolocular dimensions. The coefficient of relative dispersion about the reduced major axis for the α group is calculated as 7·57, a lower value than those obtained for the previous samples, F13627 and F13628.

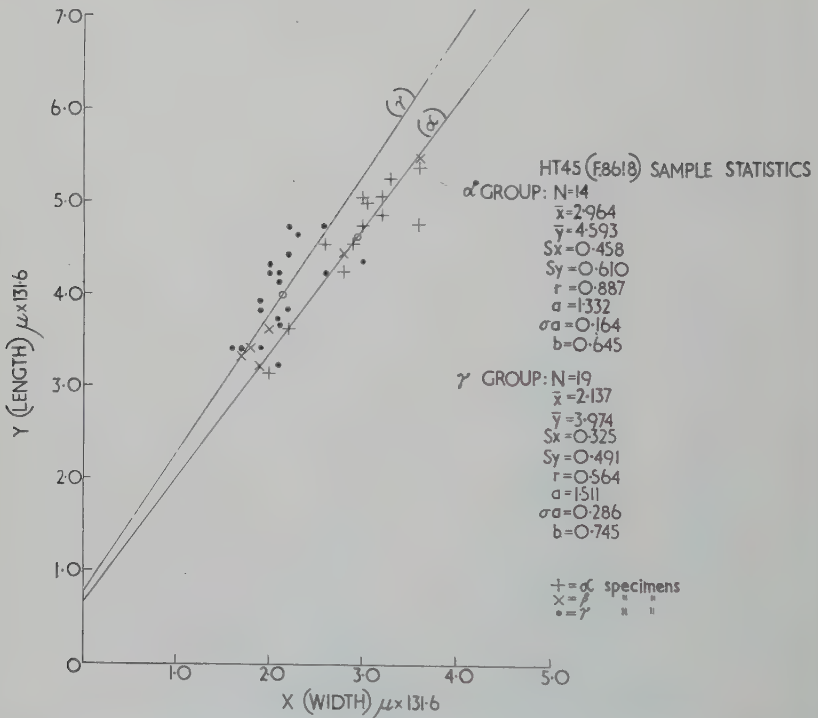


Fig. 6—Relation between Length and Width, HT45, with plotted reduced major axes and sample statistics.

HT 45 (F8618) is the highest sample available from the Tapuwaeroa Group at Tangaruhe Stream, and if the lithologic column provided by Lillie (1953, Fig. 3) is used as a basis, it must lie between 500 and 600 ft stratigraphically above F8633. As with F8633 a frequency plot (Fig. 5) of the 34 specimens examined reveals a distinctly bimodal distribution; however in this sample there is a distinct segregation, the γ group ranging from 35 to 50 μ and the α group from 64 to 87 μ in diameter. Again, compared with F8633 the modal values for both α and γ groups appears to have increased, a trend commented upon by Cosijn (1938). The growth ratio (Fig. 6) for the α group, 1·332 ($\sigma_a = 0{\cdot}164$) is not significantly different from that found for F8633 ($z = 0{\cdot}53$); furthermore, although discriminant analysis shows a difference between these groups, this is due mainly to displacement along the growth line and does not indicate different growth patterns. Although the γ groups of the two samples do not have significantly different slopes ($z = 0{\cdot}98$), there is a significant difference in the position of the lines indicating a different growth pattern.

Testing for significant differences between the growth ratios of the α and γ groups in F8618 it is found, as in F8633, that there is no evidence for this ($z = 0{\cdot}54$). It was considered that although the growth ratios of the two groups are similar, there may exist a significant positional difference. This hypothesis was tested by applying a discriminant function to the data of F8618. The function $A = 7{\cdot}4428x - 1{\cdot}8318y$ was found to best distinguish the two groups. Distance between populations (D^2) = 5·0247 and testing this gives $F_{(2,\ 30)} = 19{\cdot}597$ showing that the difference in position of the two groups is highly significant. It may also be shown that this discrimination is achieved primarily at right-angles to the growth lines. It appears, therefore, that there is a distinct movement of the γ group away from the α group in F8618; this contrasts with the situation in F8633 where the two groups show almost total overlap, discriminant analysis showing no significant difference in the growth pattern.

Finally in F8618 attention may be drawn to a third morphological group, six specimens of which were found in the sample. Whereas the α and γ groups in this sample exhibit planispiral coiling from inception, this new group, here termed the β group, typically shows the planes of coiling of two early volutions lying at angles of between 80° and 100° to that of the later chambers, the plane shifting progressively over the course of about two whorls until a planispiral habit is reached (Fig. 18). Because of the position of these early chambers, the proloculus tends to be completely obscured and only occasional specimens which exhibit asymmetries of coiling permit its observation. A section of a β specimen from a Teurian sample F3250A (Fig. 17) reveals that the first and second chambers actually closely embrace the proloculus whilst lying in the same plane of coiling as that of the outer chambers. The scatter diagram for F8618 (Fig. 6) shows that the length and width dimensions of the β group are such that they overlap both the α and γ groups.

To the south along the Whangai Range two samples collected from Te Tohe Stream by Mr A. M. Quennell appear to illustrate the same sequence of *Rzehakina* faunas F5321, a dark grey siltstone sample, carries α and γ groups visually similar to F8633. Above this, but still below the Whangai Formation, comes F5336 from a rusty grey sandstone horizon, in which, as in F8618 the α group appears to have larger prolocular diameters than the preceding sample, whilst the γ group seems relatively narrower than α specimens of approximately the same length. In Wairarapa, N159/501 (F8371) from a chocolate coloured siltstone in the Blairlogie district, contains forms of *Rzehakina* essentially similar to those in F8618, inflated α specimens, more elongate forms belonging to the γ group and also the distinctive β group. Mr M. C. Pick, collector of the sample, reports that although the lithology closely resembles that of the Waipawa Black Siltstone, the sample was taken from beds stratigraphically below the Whangai Formation. As *Dorothia elongata* Finlay also occurs in the limited fauna it is probable that these beds represent a southward continuation of the Tapuwaeroa Group of the Dannevirke area.

In Marlborough several faunas bear close similarity to those described from Tangaruhe Stream. K29 is from the Woolshed Shale of the Kekerengu district (MacPherson, 1951), whilst S36/540 (F13753) from the same district is described by its collector, Mr G. J. Lensen, as coming from an horizon 50 ft above the base of the Whangai Formation (= Woolshed Shale of MacPherson, 1951). In the latter sample, α and β groups are well represented together with several γ specimens in which the first two chambers are coiled on a plane lying approximately at 60° to that of later chambers. This appears to be the incipient stage of a type of coiling found in the γ group in the Teurian.

In the northern portion of the Eastern Basin, the sequence exposed in Wairongamai Stream has been designated by Fleming and Wellman in Fleming (Ed.), 1959, p. 378, as type locality for the Tapuwaeroa Group. Here *Rzehakina* is first represented by several specimens in sample N71/507 (F7864) from an horizon between 2,000 ft and 3,000 ft below the *Ostrea lapillicola* Beds and above the horizon of *Inoceramus bicorrugatus* Marwick. Lithology is recorded by the collector, Dr H. W. Wellman, as Mangaotane Mudstone, but the age of the sample is at present in doubt. Although several samples are available from the *Ostrea lapillicola* Beds, *Rzehakina* has not yet been found at this horizon. In sequence above the *Ostrea lapillicola* Beds, N71/511 (F7902) contains poorly preserved specimens of *Rzehakina*; however, in the succeeding sample (N71/512, F7903) α specimens are readily distinguishable from the planispirally coiled γ group. Although N71/513 (F7904) has a poor representation of the genus it is notable that specimens belonging to the β group are present together with *Dorothia elongata* Finlay. Although the samples available from Wairongamai Stream bear poor faunas and further sampling is desirable, the sequence of *Rzehakina* faunas, nevertheless, appears to approximate to that of Tangaruhe Stream.

The formation overlying the Tapuwaeroa Group and perhaps in some areas partially equivalent to it, is represented throughout much of the Eastern Basin by the lithologically distinctive Whangai Formation (Quennell and Brown, 1937) ranging in age from probably the upper part of the Haumurian into the Teurian. Microfaunas from this formation are on the whole sparse and although *Rzehakina* is present in many samples, the material is inadequate for biometric work. Again, the richly fossiliferous upper Haumurian near Pukehou (N141/533, F9617) contains only a poor representation of the genus.

Although the section exposed in Puketoro Stream is structurally complicated (Mr M. C. Pick, pers. comm.) attention may be given to samples collected though the Whangai Formation from this locality by the New Zealand Petroleum Co. Sample 50, approximately 350 ft above the base of the Whangai, has α and simple planispirally coiled γ groups represented. This situation continues in sample 48. In sample 40 still Haumurian in age, the β group appears, while in the lowest Teurian sample – 35 – all three groups are well represented, with γ specimens showing early chambers lying on a plane which is at an angle to the plane of later coiling. Sample 32, 150 ft above 35 again carries good specimens of all three groups: above this sample the section is again faulted.

In summary, there appears this sequence of *Rzehakina* populations in the Haumurian to basal Teurian of the Eastern Basin: stratigraphically low samples in which α and γ groups alone are present, with little morphological distinction between the groups other than prolocular dimensions; higher samples in which the morphological distinction between these groups, in terms of length and width measurements, becomes much more definite and in which the β group is often present. At about the same level the coiling of the early chambers of the γ group begins to depart from its previous planispiral habit.

(3) *Samples of Teurian age*

A Teurian sample studied in detail is F3250A from light coloured, mottled marls, associated with siliceous shales at the mouth of Tuparoa Stream, Waipiro S.D. The relative position of this sample within the Teurian cannot be established. Considering firstly the size of the proloculus, a frequency plot of the combined α and γ groups (Fig. 7) clearly demonstrates

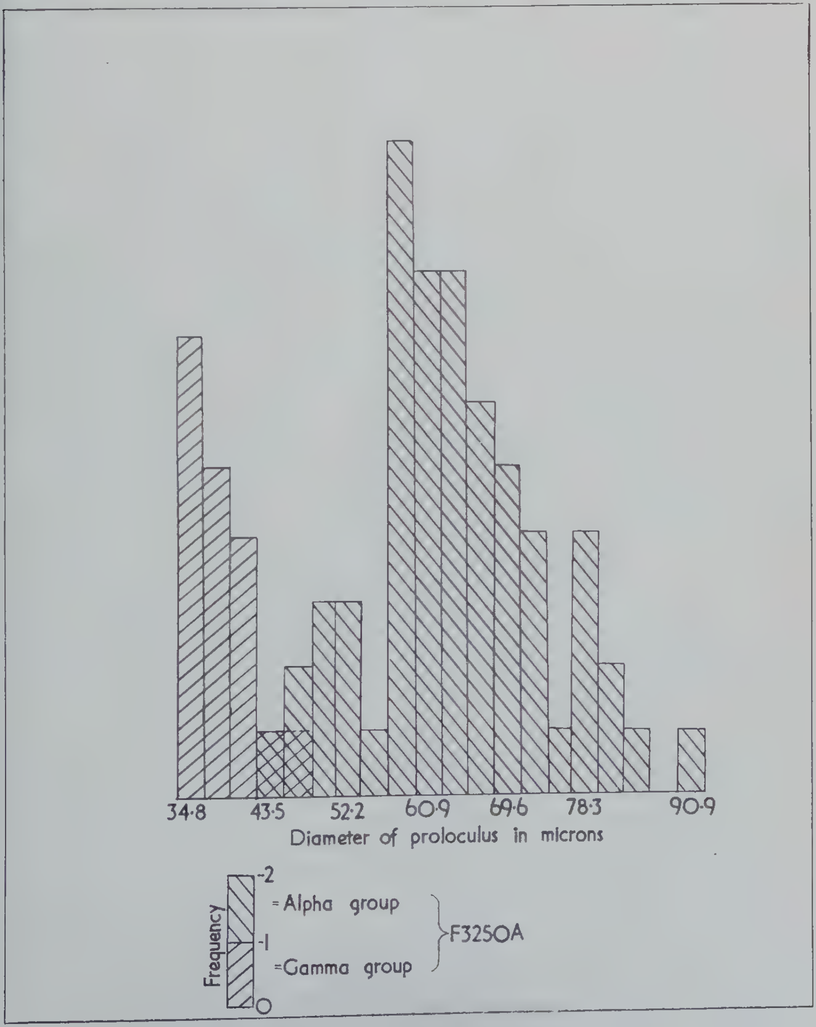


FIG. 7—Distribution of prolocular diameters, F3250A.

bimodality, the modal dimensions of the γ group being 35 μ and that of the α group being 58 μ. A larger sample would be required before much significance could be attached to the secondary peak in the γ group at 78 μ. Only four prolocular diameters belonging to β specimens were measured; these range from 23 μ to 40 μ.

As specimens in this sample are particularly well preserved with interior detail clearly apparent when the specimens are submerged in glycerine, investigation was made into the relationship of prolocular diameter to the rate of expansion, with growth, of homologous portions of successive chambers. Thompson (1952, p. 854) has pointed out that several workers have demonstrated that foraminiferal tests closely resemble logarithmic spirals in their form of growth. However, as Glaessner (1945) has remarked, the lack of septation reduces the only positive evidence for periodic growth in *Rzehakina* to the invariable position of the aperture at one of the narrow ends of the test. This being the case, some attempt was made to empirically establish that the expansion of chambers of *Rzehakina* can be approximated by a logarithmic series. Typically, a newly formed chamber expands rapidly in diameter from its inception at the apertural portion of the previously formed chamber. Position of greatest diameter is variable but is usually attained in the first third of the chamber length. From this position there ensues a gradual tapering off towards the aperture. When the succeeding chamber is formed, the chamber diameter expands slightly over a short distance to form a flange on to which the new chamber develops (Fig. 14). This position of minimum chamber diameter, actually the site of previous apertures, was selected as a site for measurement because of its fixed position and obvious homologous nature. For measurement, specimens were submerged in glycerine and examined under transmitted light using a magnification of × 360. An ocular micrometer scale was employed. Table 1 shows that the expansion of successive apertures of an α specimen, F3250A, can be approximated by a logarithmic series with common ratio $\rho = 1{\cdot}229$.

TABLE 1—Measured and calculated values for expansion of apertural necks, α specimen F3250A

Chamber No.	Measured Diameter Aperture (μ)	Computed Diameter $\rho = 1{\cdot}229$
1	7.25	......
2	8.70	8.91
3	11.60	10.95
4	14.50	13.45
5	18.15	16.53
6	21.05	20.32
7	24.65	24.96
8	29.00	30.68
9	37.70	37.70

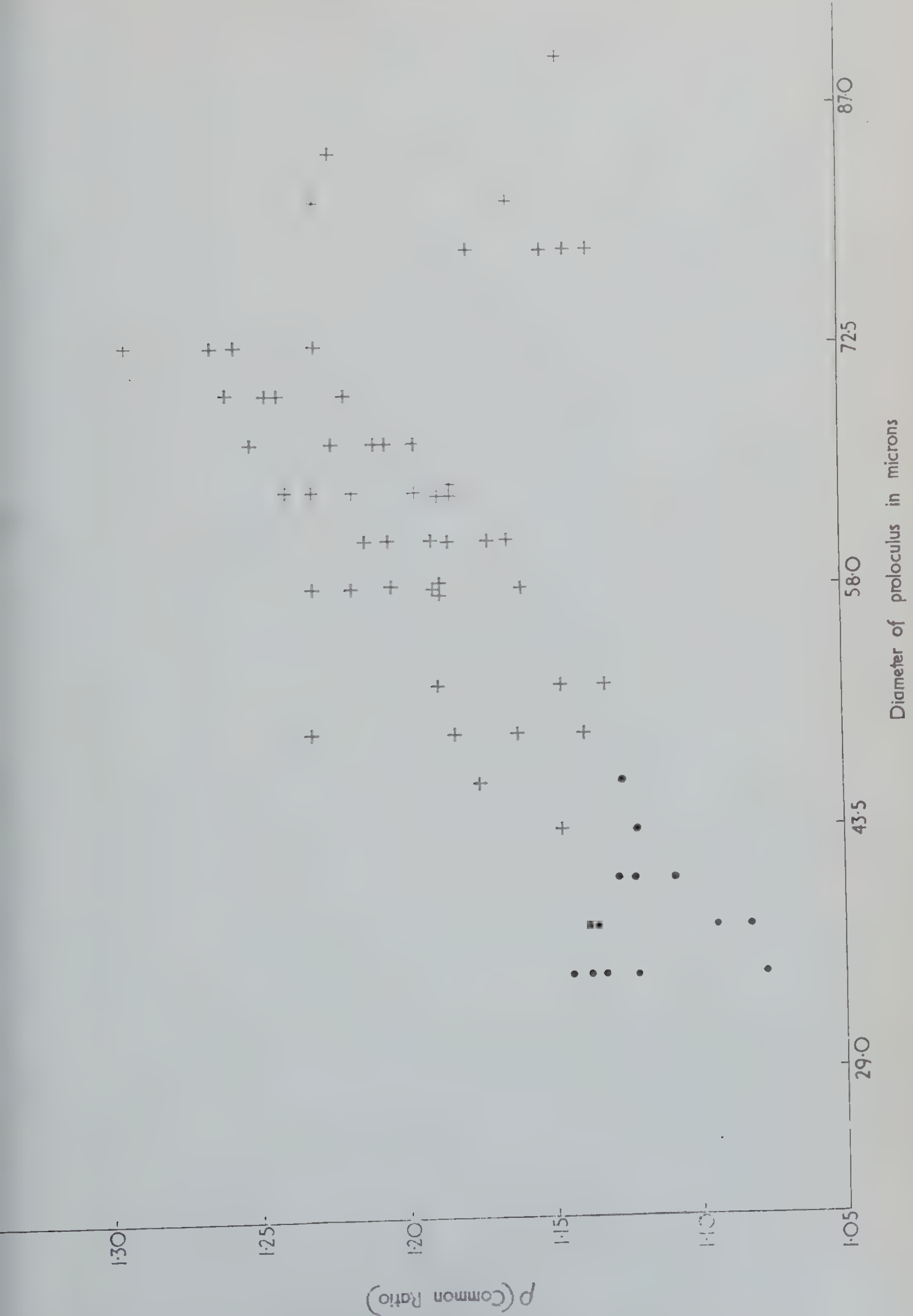


FIG. 8—Relation between prolocular diameter and ρ, common ratio, F3250A.

Once it was established that a logarithmic series provided a reasonable fit for experimental data, the procedure was modified to measuring the first and last members of a series of n apertural necks and finding ρ by taking (n — 1) root of the ratio last apertural neck: first apertural neck. This procedure is admittedly crude, considering Rhumbler's observation (quoted by Thompson, 1952, p. 858) that the ratio in some instances may be subject to a small secondary fluctuation. However, in view of the accuracy of measurement made here ($\pm 1\ \mu$) the method used appears a reasonable approximation. The results of this study are shown graphically in Fig. 8 for the combined α and γ groups. Although for a given prolocular diameter there may be considerable variation in values for ρ, the overall trend to higher values with increase in prolocular diameter is clearly demonstrated, at least up to a value of 73 μ. It becomes obvious, therefore, that the slim chambers of the γ group, exhibiting a slow rate of expansion, are a result of the small prolocular dimensions of this group. Moreover, the method appears to afford a means, accepting a linear relation between prolocular diameter and ρ, of assessing the probable size of proloculus in the β group. The mean value of ρ for 45 β specimens was found to be 1·11, the range being from 1·06 to 1·24. This would suggest that the prolocular dimensions of the β group are approximately that of the γ group in which the mean value of ρ for 15 specimens is 1·12 (range 1·08 – 1·14). Finally, attention may be drawn to the small group of specimens having prolocular diameters greater than 85 μ. These tend to have relatively lower values of ρ in relation to prolocular diameters than is the case with the remainder of the α group with diameters under 85 μ. Morphologically these specimens are often distinguished by their smaller number of chambers (Fig. 23) although this rule is not invariant.

The most notable feature of the growth lines plotted for the three groups in F3250A (Fig. 9) is the large value for a in the γ group ($a = 2{\cdot}408$ $\sigma_a = 0{\cdot}275$). In F8633 the growth lines for the α and γ groups were not significantly different; in F8618 the γ group had become considerably attenuated with the result that although the growth ratios for the two groups could not be shown to be different, the lines, positionally, were clearly distinct. In F3250A this trend appears to continue to such an extent that the values of a for the two groups are significantly different (z = 3·43). Comparison of slope values for F8618 and F3250A γ groups shows a significant difference (z = 7·32). Again, whereas coiling in F8618 γ group is planispiral, the same group in F3250A has the earliest chambers coiled on planes varying from approximately 60° to 90° to the plane of coiling of later chambers (Fig. 16), a feature first observed to occur in its incipient form in F13753 from Marlborough. The α group appears much more conservative in its growth pattern. The growth ratio for F3250A is 1·436 ($\sigma_a = 0{\cdot}065$) as compared with 1·332 ($\sigma_a = 0{\cdot}164$) for F8618. These values do not differ significantly (z = 0·59) but there is a small difference in the position of the lines which because of the large sample is significant at the 5% level. As in F8618, the β group exhibits growth features similar to those of the α group. Significant differences in the value of the growth ratios of the groups cannot be shown (z = 1·72); however, there is a significant difference in their position.

In Dannevirke Subdivision at Poanui Point, a Teurian sample N146/583

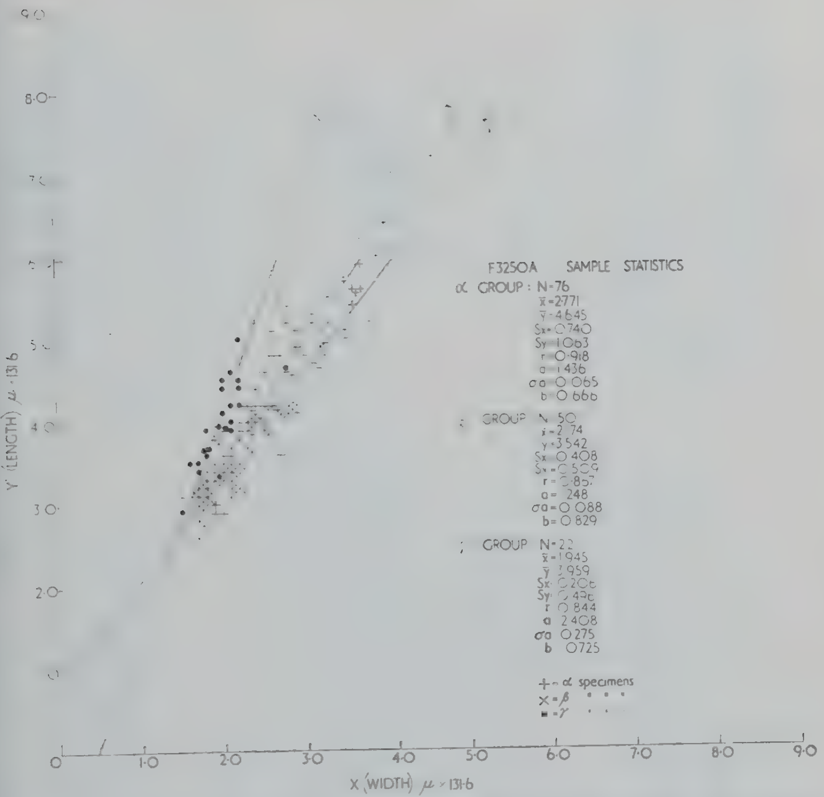
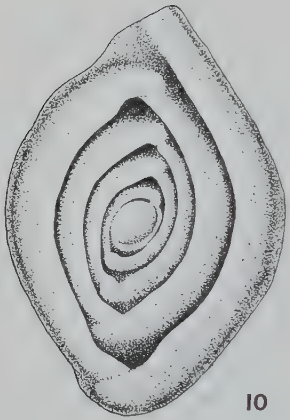


FIG. 9—Relation between Length and Width, F3250A, with plotted reduced major axes and sample statistics.

(F13636) from red and green bentonitic mudstones (Lillie 1953: 40) contains a γ group showing rather different growth characteristics to those displayed in F3250A. Whereas growth ratios of the α and γ groups in the latter sample were significantly different, here this cannot be shown ($z = 1{\cdot}16$). But while the growth ratios are similar, the position of the γ reduced major axis is clearly offset from the α group and in fact very little overlap of the dimensions of the two groups is shown in Fig. 24. A discriminant function has been calculated to test whether or not the positional difference between the two groups is in fact significant. The linear function $A = 10{\cdot}7507x - 7{\cdot}3883y$ best distinguished the α and γ groups. Distance between the groups as estimated by the samples, $D^2 = 8{\cdot}6162$; this value is highly significant ($F_{(2,\,40)} = 44{\cdot}572$). This discrimination is obtained very largely by displacement normal to the growth lines.

Growth ratios of the α groups of F13636 ($a = 1{\cdot}204$) and F3250A ($a = 1{\cdot}436$) are different at the 5% level but the value for z ($z = 2{\cdot}49$)



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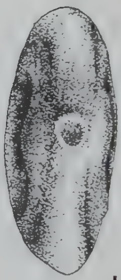

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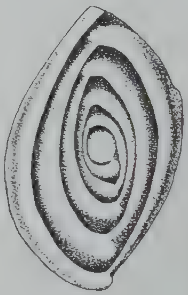

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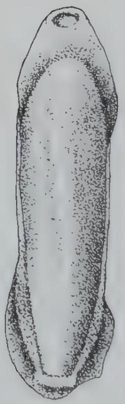

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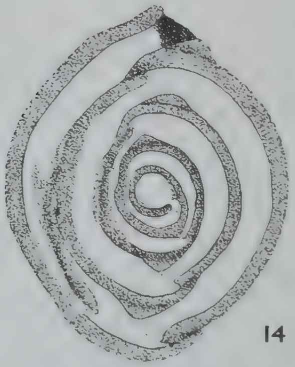

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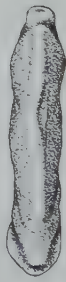

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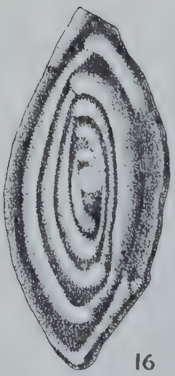

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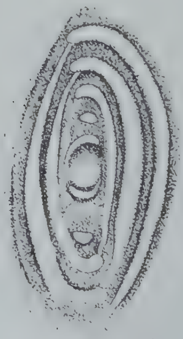

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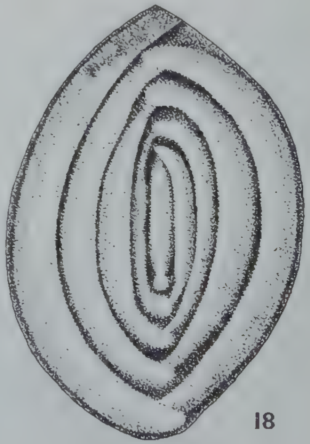

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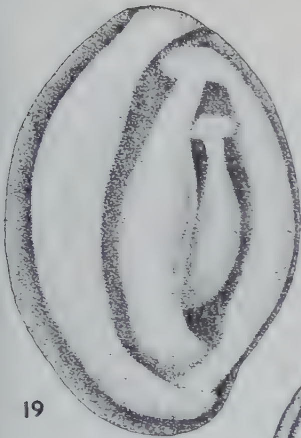

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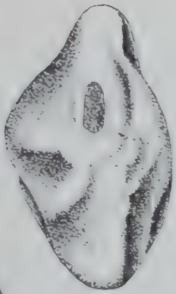

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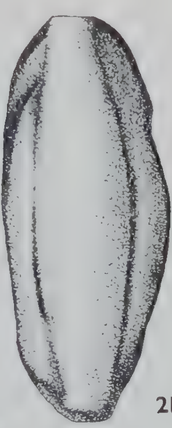

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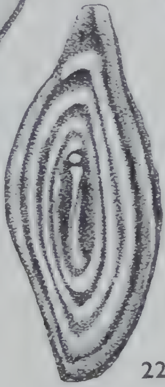

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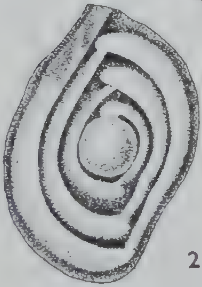

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Rzehakina epigona (Rzehak) Figs 10–18

FIG 10—Specimen (N.Z.G.S. Cat. No. FP1291) from alpha group, HT58B, F8633, Tangaruhe Stream. × 100.

FIG. 11—FP 1291, apertural view. × 100.

FIG. 12—Specimen (N.Z.G.S. Cat. No. FP1292) from gamma group, HT58B, F8633, Tangaruhe Stream. × 100.

FIG. 13—FP1291, side view. × 100.

FIG. 14—Longitudinal section of a specimen (N.Z.G.S. Cat. No. FP1293) from alpha group 561, Puketoro Stream. × 100.

FIG. 15—FP1292, side view. × 100.

FIG. 16—Specimen (N.Z.G.S. Cat. No. FP1294) from gamma group F3250A. × 100.

FIG 17—Longitudinal section of a specimen (N.Z.G.S. Cat. No. FP 1295) from beta group, F3250A. × 100.

FIG. 18—Specimen (N.Z.G.S. Cat. No. FP 1296) from beta group, F3250A. × 100.
—*R. C. Brazier, del.*

Rzehakina epigona (Rzehak). Figs 19–23.

FIG. 19—Specimen (N.Z.G.S. Cat. No. FP1297) from delta group, N19/595, F8745. × 100.

FIG. 20—FP1297, apertural view. × 100.

FIG. 21—FP1297, side view. × 100.

FIG. 22—Specimen (N.Z.G.S. Cat No. FP1298) from gamma group, F5391. × 100.

FIG. 23—Specimen (N.Z.G.S. Cat. No. FP1299) from alpha group, F3250A. × 100.
—*R. C. Brazier, del.*

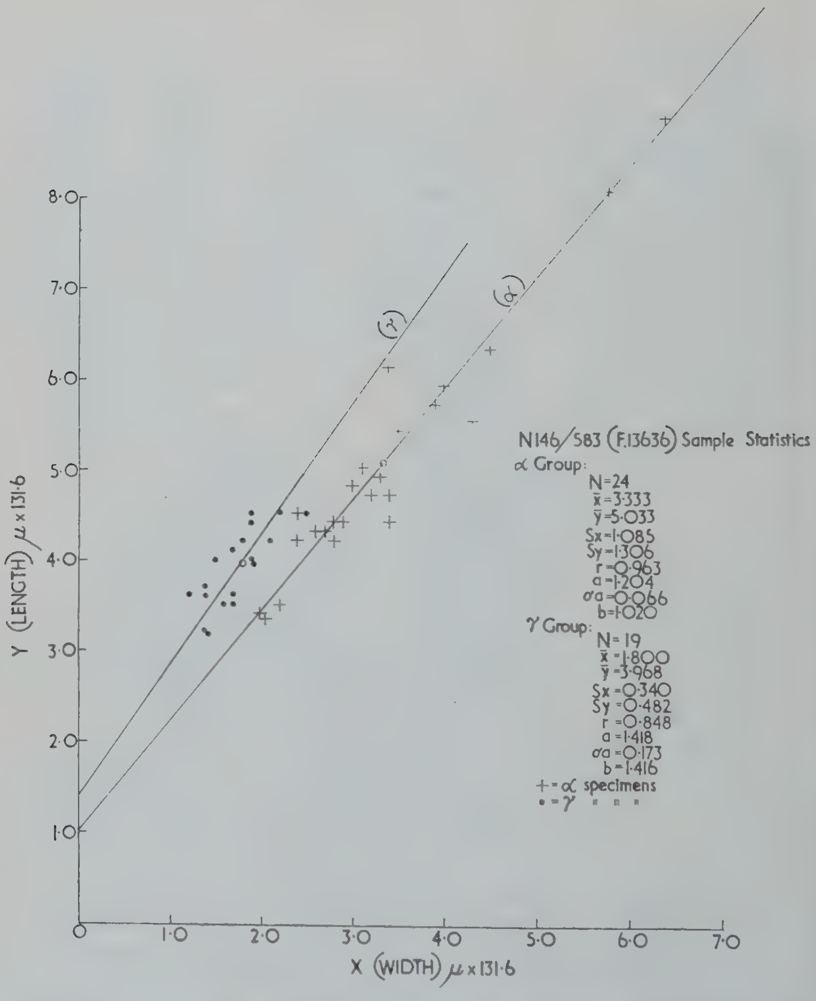

FIG. 24—Relation between Length and Width, N146/583, with plotted reduced major axes and sample statistics.

does not exceed the 1% level. Gamma groups, however, are significantly different in slope ($z = 3{\cdot}05$), this value exceeding the 1% level. An important distinction between the two samples is the absence in F13636 of representatives of the β group.

Little is known about the stratigraphic relationships of the next sample studied, F5391, from a red shale horizon outcropping at Armstrong Rd, Waitangi, but faunally the presence of *Eggerella columna* Finlay together with *Tappanina glaessneri* (Finlay) suggests that its age is at least uppermost Teurian and probably no younger than basal Waipawan. As in F13636 from Poanui Point, only α and γ groups may be distinguished. As the scatter diagram illustrates (Fig. 25), the growth ratios for the two groups are closely similar, 1·483 ($\sigma_a = 0{\cdot}112$) for α and 1·838 ($\sigma_a = 0{\cdot}147$) for γ. While these two values cannot be said to differ significantly, the value for $z = 1{\cdot}92$ is close to the 5% level. However there is a marked difference in the position of the plotted lines, and no overlap in the dimensions of the two groups is to be seen in Fig. 25. The relation between the reduced major axes for the two groups is thus very similar to that seen in F13636. In the γ groups of F5391 and F13636, the growth ratio is higher for the Waitangi sample, but this difference is not clearly significant ($z = 1{\cdot}85$); however there is a positional difference significant at the 1% level.

If F3250A, F13636 and F5391 are compared, it is clear that between these samples there is progressively less overlap of the length and width dimensions of the α and γ groups. In F3250A overlap of these dimensions occurs in the smaller members of the groups; in F13636 such overlap is reduced although it could occur in very small individuals. However the values of the growth ratio and initial growth index in F5391 are such that it is very highly improbable that any overlap in dimensions could occur. It should be emphasised that although there appears to be a morphologic

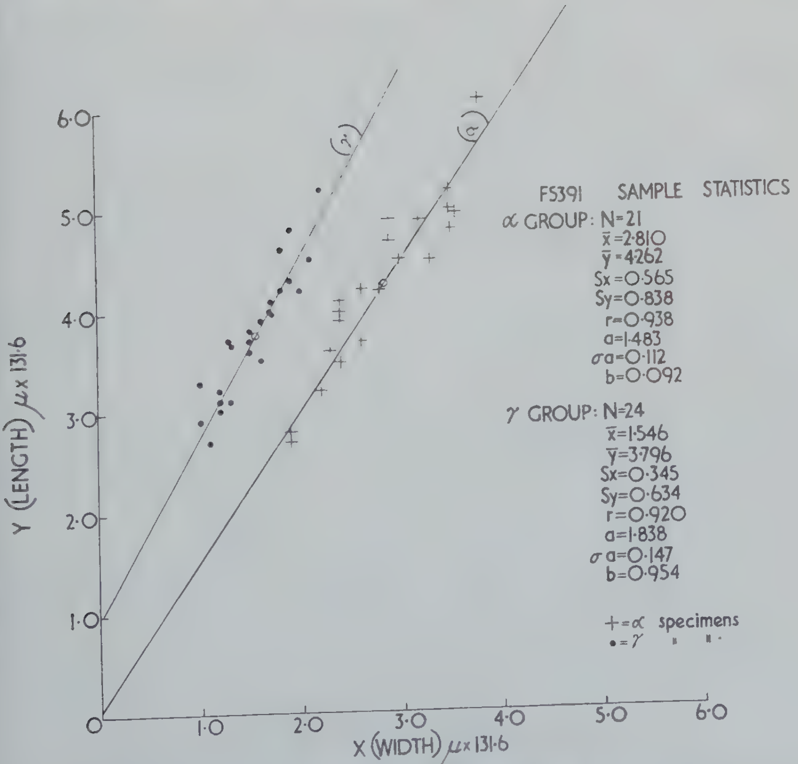

FIG. 25—Relation between Length and Width, F5391, with plotted reduced major axes and sample statistics.

sequence from F3250A through F13636 to F5391 independent stratigraphic or paleontologic evidence for this is lacking except for the presumably upper Teurian horizon from which F5391 was drawn.

Study of available material has revealed several probable upper Teurian samples from the Eastern Basin in which *Rzehakina* is represented by α and attenuated γ groups comparable to those in F5391. These include F4012 from the same horizon at Waitangi as F5391, and F6292 from Waimarama Beach, southern Hawke's Bay. The latter, from a bentonite, carries *Eggerella columna* Finlay and may be presumed to come from an horizon high in the Teurian. F6293, described as a "shattered white mudstone associated with red beds", from Mangataikapua River carries a similar assemblage. In the upper portion of the Wairongamai Stream section, F11491 from 2 ft above the top of the black siltstone horizon and F11492, 10 ft above this datum, contain well differentiated α and γ groups together with, in F11492, undoubted β specimens. It is significant to record the presence of *Eggerella colmuna* Finlay in F11492, this being at present the only known occurrence of β specimens in association with this species. In this section the Teurian-Waipawan boundary appears to lie at least 100 ft above the top of the black siltstone horizon.

In the Te Uri Stream section, Dannevirke Subdivision, although microfaunas are well developed (Hornibrook and Harrington, 1957), *Rzehakina* is not well represented. In N150/522 (F10014) α and β groups may be recorded together with several γ specimens which are notable in that there is only a slight tendency for the earliest chambers to lie in planes at angles to later coils. Again attenuation of these specimens is not nearly so marked as those from Poanui Pt or Kate's Quarry (N151/1001, F13657). This observation tends to support the contention put forward by Hornibrook and Harrington (1957, p. 664) that the 175 ft of grey siltstone forming the type Teurian beds, is separated by a fault from the younger beds of the section. The Kate's Quarry sample (N151/1001) mentioned carries only α and γ groups, the latter being elongate and displaying rotation of the plane of coiling of the early chambers. An associated sample from the same locality (N151/1000, F13656) contains specimens which may be referable to *Eggerella columna* Finlay. Elsewhere within the Dannevirke Subdivision Upper Teurian time is represented commonly by black siltstones such as occur at Waipawa, south of Takapau and at Mangatarata (Lillie, 1953). Restricted microfaunal assemblages are encountered in these beds (Hornibrook and Harrington, 1957) which appear to provide an environment unsuitable for *Rzehakina* as well as for many other genera of Foraminifera.

Little information is available from Wairarapa, but mention may be made of N168/579 (F9709) discussed by Waterhouse and Bradley (1957). This sample, from the Mungaroa Limestone, bears attenuated γ specimens (Fig. 26) with a high growth ratio, $a = 2{\cdot}400$ ($\sigma_a = 0{\cdot}389$) comparable to that displayed by the γ group in F3250A. As only two α specimens were found in the small sample it is difficult to judge the distance between the two groups. The associated fauna, including *Pseudovalvulineria infrafossa* (Finlay) and *Tappanina glaessneri* (Finlay), suggest an uppermost Teurian to basal Waipawan age. It is very doubtful if any significance can be placed on the occurrence of *Clavulinoides instar* Finlay in this sample as similar

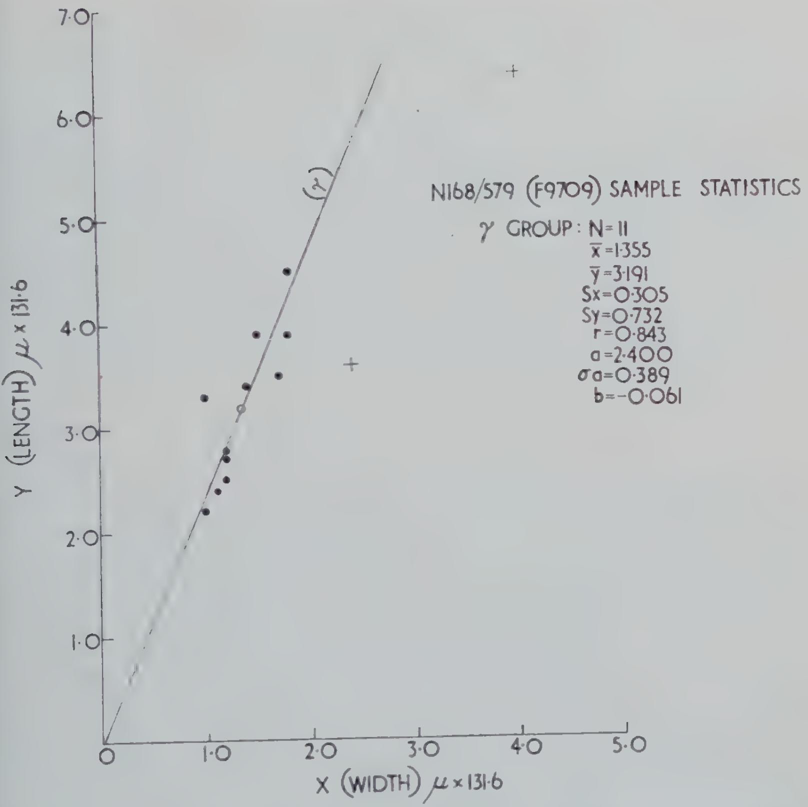

FIG. 26—Relation between Length and Width, N168/579, with plotted reduced major axis and sample statistics.

forms occur in the red shale faunas of Waitangi (F5391). In fact, faunally, there is no real evidence to suggest that this sample comes from a redeposited horizon such as Waterhouse and Bradley (1957, p. 527) envisage for the Mungaroa Limestone.

Finlay (1939) listed several records of the genus in post-Teurian samples, some of which may now be reviewed. F3286 from Pouawa Dome, besides containing a Bortonian fauna, has also yielded *Bolivinoides dorreeni* Finlay, an Haumurian species, *Elphidium hampdenensis* Finlay and *E. saginatum* Finlay, Heretaungan and Porangan indices respectively. Large specimens belonging to the α group of *Rzehakina* occur in this sample. F3290 from the Whangara Uplift contains a similar mixture of faunal elements with very rare β and γ groups occurring with *Uvigerina hortotara* (Finlay), *Elphidium hampdenensis* Finlay and *Bolivinoides* aff. *dorreeni* Finlay.

In southern Hawke's Bay a sample from Stoddart's bentonite (F8932) containing Bortonian species, *Cibicides tholus* Finlay *Nuttallides trumpyi* (Nuttall) and *Globigerapsis index* (Finlay), has rare specimens of *Rzeha-*

kina. These are all γ specimens, poorly preserved, with interior detail unobservable. It appears however that the possibility of contamination cannot be ruled out as several samples from this horizon contain specimens of the Paleocene *Controchammina depressa* Finlay. In the Te Uri section, N150/526 (F10018), a type Waipawan sample, contains several small γ specimens. In southern Wairarapa α and possibly γ groups occur in N166/561 (F7687), probably basal Waipawan, together with *Aragonia* aff *aragonensis* (Nuttall), *Bolivinopsis* aff *compta* Finlay and *Tappanina glaessneri* (Finlay); *Globorotalia crater* Finlay is not present in this sample. N163/504 from a Waipawan or Mangaorapan horizon also contains a probable γ specimen.

In review, the situation remains similar to that discussed by Finlay; in the collections available for this study from the Eastern Basin there is still no clear evidence from an uncontaminated sample for *Rzehakina* ranging into strata younger than Waipawan.

Rzehakina IN NORTHLAND

In contrast to Finlay's sole record from F1283, Silverdale, more detailed collecting within the past decade has yielded many faunas bearing *Rzehakina*. The earliest record at present known is from an Arowhanan exposure near Whangape. This sample (N13/501, F10114) is from blue grey silty mudstone overlain by beds bearing *Inoceramus rangatira* Wellman. Preservation is poor and interior detail is unobservable in the small leaf like specimen. However the shape and development of small callus knobs at the junction of the penultimate and final chambers are typical and there is little doubt that the specimen must be referred to *Rzehakina*. Rare specimens of *Rzehakina*, similar to F10114 occur in N15/584 (F8261) from a Teretan horizon (*Inoceramus nukeus* Wellman). Another small population occurs in N14/610 (F8680) taken from an horizon probably underlying beds containing *Ostrea lapillicola* Marwick. This may be a Piripauan horizon but positive evidence is wanting.

In contrast with the rarity of *Rzehakina* in the Piripauan Stage and Raukumara Series, the genus becomes widespread in Haumurian to Teurian strata of Northland, colonising most environments from the coarsely laminated sandstones of N28/652 (F9073) to the very fine-grained open water facies represented by N10/674 (F7979).

The first sample studied in detail, F9073, has obscure stratigraphic relationships but the presence of *Dorothia elongata* Finlay dates it as Haumurian. Twenty-seven α specimens were measured, these including some very large individuals up to 1·38 mm in length (Fig. 27). As a greater range of values was obtained from this sample in the α group than from others studied, a test of goodness of fit of a line of the type $y = ax + b$ was applied to these data (Table 2). This table shows that there is no reason to doubt that a straight line can be satisfactorily fitted to the data.

The growth ratio for the α group of this sample ($a = 1{\cdot}090$ $\sigma_a = 0{\cdot}052$) is the lowest encountered in this study. The slope is significantly different from the Teurian sample (F3250A) studied from the Eastern Basin ($z = 4{\cdot}17$) but not from F8618 from the Haumurian ($z = 1{\cdot}41$); however

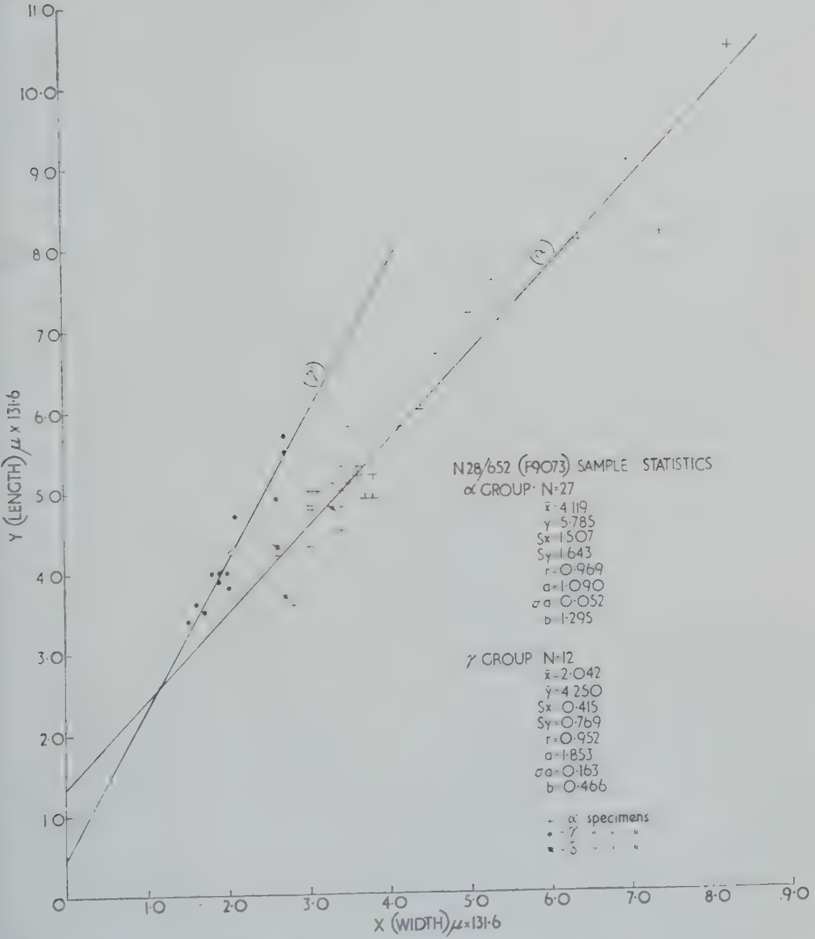

FIG. 27—Relation between Length and Width, N28/652, with plotted reduced major axes and sample statistics.

there is a positional difference significant at the 5% level. The γ group in F9073 contains individuals in which only the earliest coils lie on planes at about 60° to 70° to the later plane of coiling. In this respect the group is comparable with its age-equivalents in the Eastern Basin. The growth ratio for the γ group ($a = 1{\cdot}853$, $\sigma_a = 0{\cdot}163$) cannot be separated from the values found for the γ group in F8618 ($z = 1{\cdot}05$) but is significantly different from F8633 ($z = 3{\cdot}14$). The slopes of the α and γ groups in the sample are markedly distinct ($z = 4{\cdot}46$), the low value for the growth index of the α group contributing much to this result. In this respect it should be mentioned that Haumurian samples showing such a clear distinction between α and γ groups have not been encountered in the Eastern Basin.

TABLE 2—Analysis of variance table testing adequacy of linear and curved regression lines, α group F9073

Source of Variation	Sum of Squares	d.f.	Mean Square
Total	70·1541	26	
Deviation from linear regression	4·3364	25	0·1735
Linear regression	65·8177	1	65·8177

$$F_{1,\,25} = \frac{65\cdot8177}{0\cdot1735} = 37\cdot94 \text{ highly significant.}$$

Deviation from linear regression	4·3364	25	
Deviation from curved regression	4·2356	24	0·1765
Curvilinearity of regression	0·1008	1	0·1008

$$F_{1,\,24} = \frac{0\cdot1008}{0\cdot1765} = 0\cdot571 \text{ not significant.}$$

∴ Regression line of form $y = \alpha x + \beta$ is a good fit and line of form $y = r + qx + px^2$ is not significantly better.

Although only two β specimens were found in F9073 these appear very similar to those in Eastern Basin upper Haumurian-Teurian samples. Also occurring in this sample are four specimens exhibiting features not seen previously. Viewed under glycerine (Figs. 19, 20, 21) the chamber layout consists of two coils lying side by side on planes varying from 70° to 110° to that of the width of the test, followed by a third and final coil in that plane. Geometrically, coiling is essentially similar to β specimens except that there is only one coil in the plane of later coiling; moreover, expansion of chambers is much more rapid and progresses much further than is seen in β group specimens. A sectioned specimen was found to possess a large proloculus 78 μ in diameter. Fig. 27 shows that the gross dimensions of these δ group specimens falls within the range of variation exhibited by the α specimens in the sample. It appears that wall structure of the chambers of the δ specimens is quite comparable with that of α, β, and γ groups, consisting of very fine arenaceous material in a presumably siliceous cement, the test being given a very smooth vitreous appearance by an external finish of cement. No tooth has been observed in the simple aperture (Fig. 20) and there seems no reason, bearing in mind the types of coiling observable in the α, β, and γ groups, why these specimens should not be assigned to *Rzehakina*. The δ form has been found only in one other Northland sample, N19/595 (F8745), from well bedded red and green shales in the Tangowahine Valley. Stratigraphic position is obscure and the small microfauna present can only be aged as Haumurian to Teurian. Accompanying the group are α and γ groups; no β specimens occur. In the many samples examined from the Eastern Basin containing *Rzehakina.* only one specimen of this group has been found (N154/556, F13856 Mh-t).

A Teurian sample from Northland which has been measured is N19/545 (F9970) from light blue siltstone outcropping in a tributary of Onetai Stream. Eighty-eight α specimens were studied, 51 of which had measurable proloculi. Fig. 28 shows the distribution of values obtained. It is informative to compare this distribution with that found for the α group of F3250A (Fig. 7). In both a large range of values is found; 43 microns to 90 microns in F3250A and 40 microns to 101 microns in N19/545. Modal values differ in that the mode for F3250A is at 58 μ and that for N19/545 is at 78 μ. In both samples attention may be drawn to those speci-

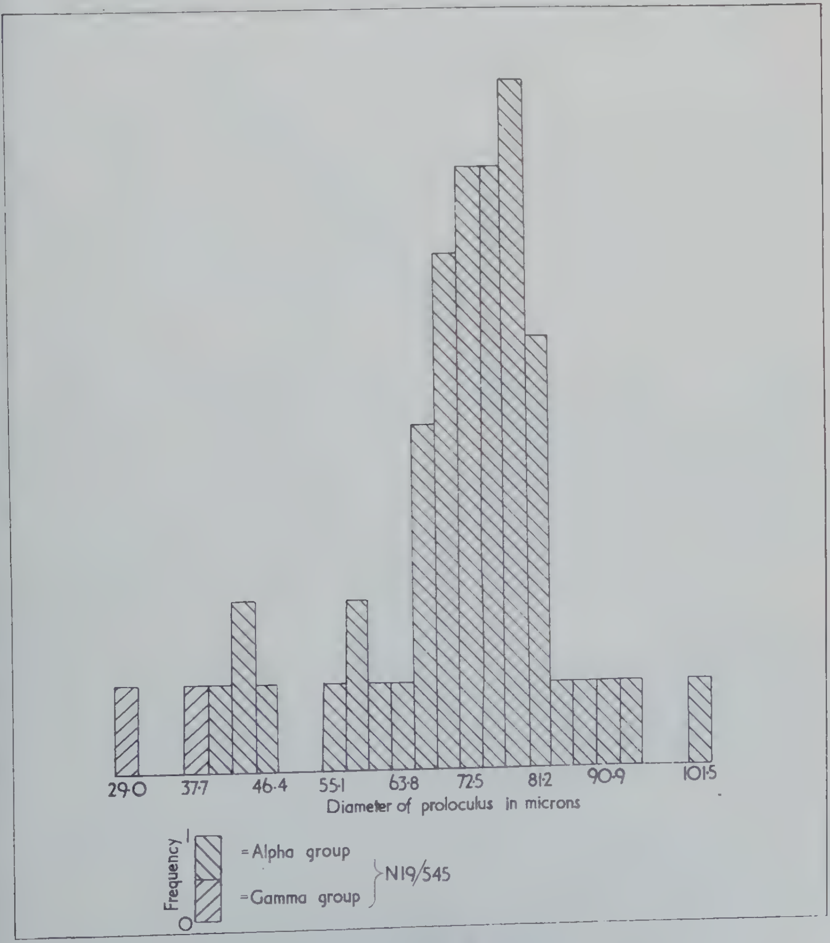

FIG. 28—Distribution of prolocular diameters, N19/545.

mens with proloculi of small dimension. Qualitatively these appear usually to contain more chambers; in this respect the position seems to be the reverse to that obtaining in specimens with very large proloculi as these tend to have fewer chambers than normal. There is clearly scope for investigation into this relationship in large samples containing well preserved specimens. Although there is a lacuna in the distribution for N19/545 between 46 and 55 μ, there appears little reason, in view of the small frequencies involved on either side, to attach any significance to this feature, no counterpart of which occurs in F3250A.

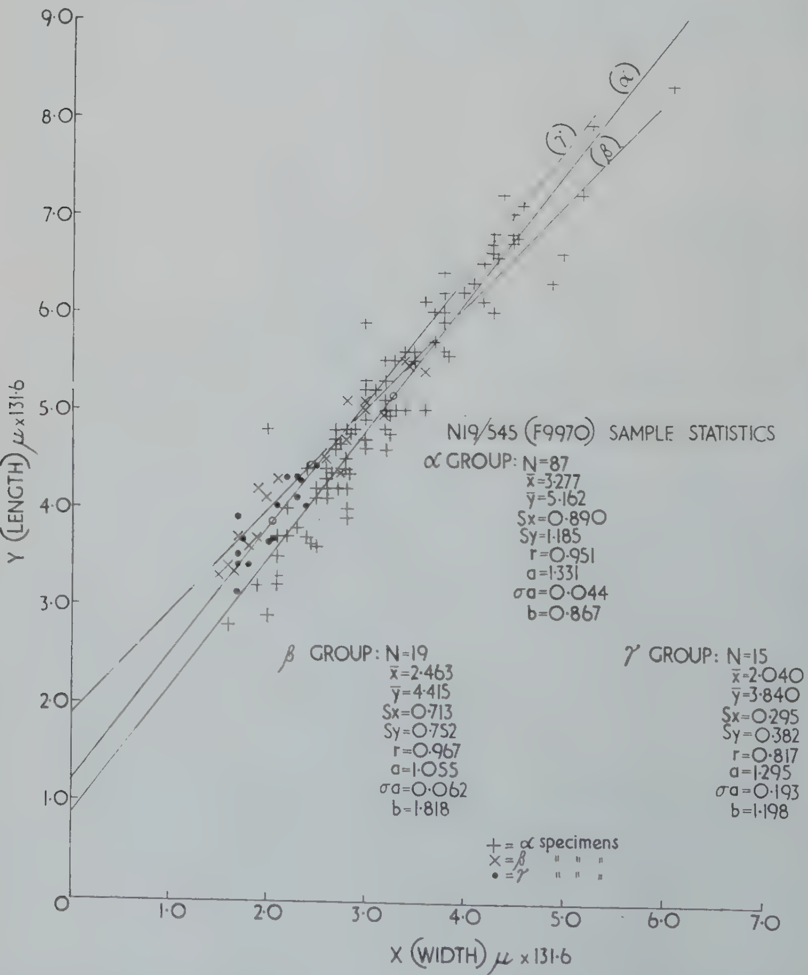

FIG. 29—Relation between Length and Width, N19/545, with plotted reduced major axes and sample statistics.

Consideration of slope values for the groups of F9970 (Fig. 29) reveals some contrasts compared with results from previous samples. The growth ratio, a is 1·331 (σ_a = 0·044) for the α group and 1·295 (σ_a = 0·193) for the γ group. These values are not significantly different (z = 0·18). However, there is a difference in position significant at the 0·1% level. In this respect these groups may be compared with Haumurian samples such as F8618. However, it must be noted that the γ group in F9970 is not completely planispirally coiled as in F8633. In contrast with the similarity in growth ratio between α and β groups in previously discussed samples, these groups in F9970 exhibit significantly different slopes (z = 3·63), the β group having a low value for its growth ratio (a = 1·055, σ_a = 0·062).

A comparison of the β groups of F9970 and F3250A shows that slopes do not differ at the 5% level (z = 1·80), but there is a difference in position significant at the 0·1% level. The growth ratio of the α group, as Fig. 29 demonstrates, is very similar to F8633, F8618, F3250A and F5391. Delta specimens have not been found in the sample.

In summary then, this sample is primarily unusual, for a Teurian sample, in the morphological overlap of the three groups, especially in the close relation, in length and width measurements, of the α and γ groups. Coiling of the γ group is however comparable with other Teurian samples. That the lack of attenuation of γ specimens in N19 545 is not necessarily typical of all Teurian populations in Northland is demonstrated by the presence in N19/594 (Fig. 30) of several γ specimens showing considerable attenuation perhaps comparable with that seen in F3250A and F13636. It is unfortunate that this sample (N19 594) is too small to allow worthwhile quantitative study.

At this stage it is premature to decide the degree of provincialism within *Rzehakina* in the Mata Series. The sequence of secular morphological changes seen in the Eastern Basin cannot clearly be shown to apply to Northland; this may be in part due to lack of samples from sequences with good stratigraphic control. Nevertheless, at present, differences seem more outstanding than similarities -- the low value of the growth ratio found in the α group of F9073 (Fig. 31), the growth pattern similarities of α, β, and γ groups in F9970 (Teurian) compared with the segregation of the α and γ seen in F9073 (Haumurian).

Finally, attention may be drawn to two samples in which *Rzehakina* occurs with Dannevirke faunas. N20/588 (F8723) from Brewery Creek, Whangarei, bears *Eggerella decepta* Finlay and *Vulvulina zespinosa* Finlay which indicate a lower Dannevirke, perhaps Mangaorapan age, together with rare specimens of *Rzehakina*. As a single specimen of *Dorothia biformis* Finlay, an Haumurian index, also occurs in the sample, it is probable that mixing of faunas has occurred. In the case of N23/534 (F9879) from Onemama Point, although the stratigraphic position of the sample is not well known, the fauna contains *Globorotalia* aff. *crater* Finlay together with α and γ specimens which are poorly preserved. In terms of the currently employed chronology, this sample must be accepted as being no older than Waipawan; as such it marks the only occurrence, presently known, of *Rzehakina* together with *Globorotalia* of the *crater* line.

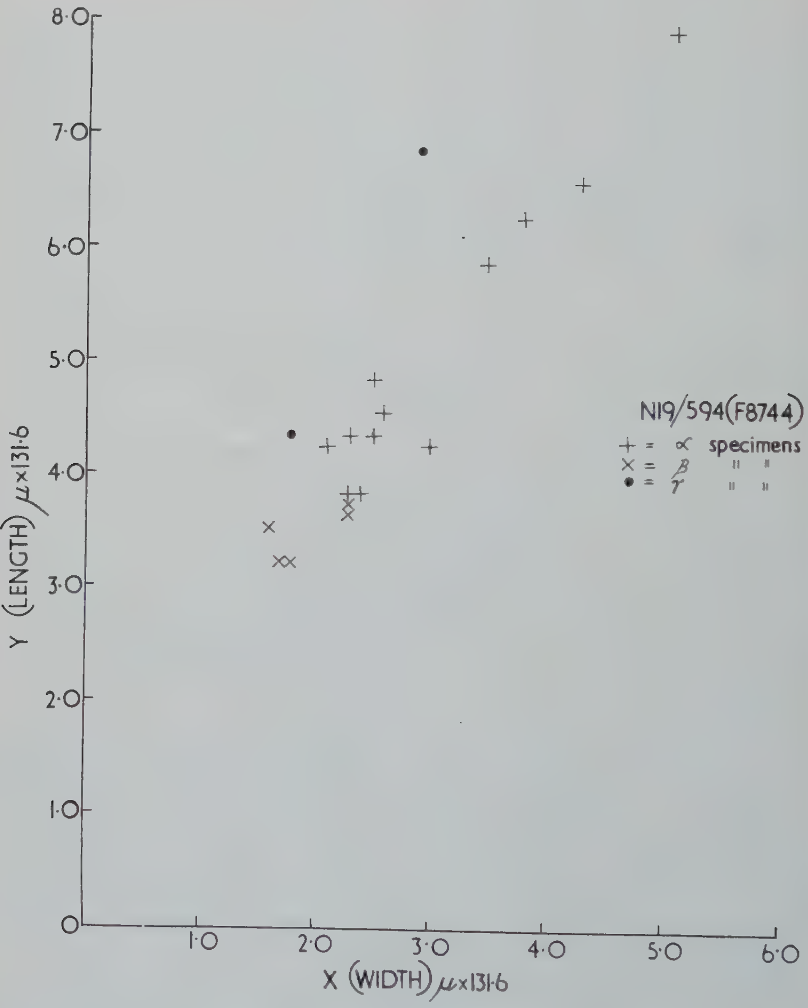

FIG. 30—Relation between Length and Width, N19/594.

SURVEY OF THE STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF *Rzehakina* IN NEW ZEALAND

In both the Eastern Basin and Northland, Raukumara occurrences of *Rzehakina* are few and sporadic. Nevertheless it is clear that in both provinces the genus occurs in samples from the base of the Raukumara Series associated with Arowhanan macro-fossils. It is not until Haumurian time, however, that the genus succeeded in widely colonising the available environments. In the lower Haumurian small populations of α and γ groups

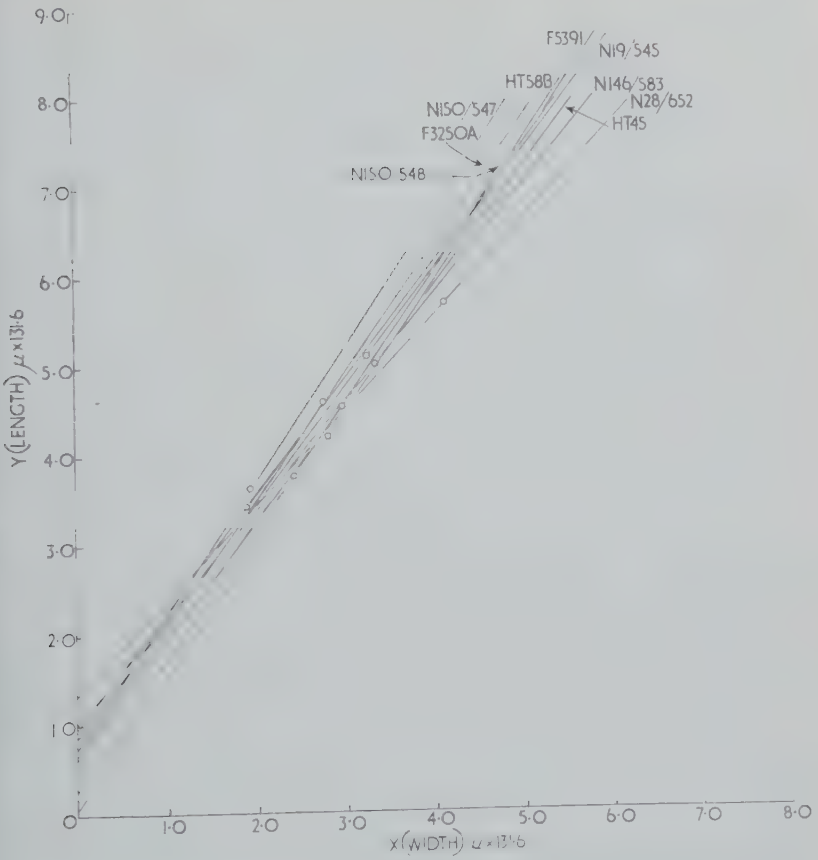

FIG. 31—Reduced major axes for the alpha groups of all samples measured.

are found in the dark siltstones and sandstones of the Tapuwaeroa Group in both Gisborne and Hawke's Bay. Later in this period, with the β form now present, *Rzehakina* came to occupy a wide range of environments. The genus persisted in presumably moderately shallow water environments throughout the Eastern Basin accompanied by wholly arenaceous microfaunas; in Wairarapa it successfully inhabited a site of chocolate shale deposition, probably a very shallow water locus. At the same time *Rzehakina* may be found represented, usually by small numbers, in samples from very fine grained whitish sediments of the Whangai Formation. In Northland the genus became common in undoubted open water environments. For example, N10/674 (F7979) has abundant specimens of *Globotruncana* sp., *Gublerina* aff. *glaessneri* Bronnimann and Brown, *Heterohelix pamkauia* (Finlay) and *Heterohelix* spp. Probably similar environments in Hawke's Bay supported lesser populations (e.g. N141/533).

Yet although *Rzehakina* was nearly ubiquitous throughout Northland and the Eastern Basin during this upper Haumurian period, a curious gap in distribution emerges when an attempt is made to trace the genus further south. MacPherson (1951) collected samples bearing *Rzehakina* from his Woolshed Shale (= Whangai Formation) and more recent work in the same district of Marlborough by Mr G. J. Lensen has increased the recorded occurrences several fold. Similarly Wellman (1955) records the genus from the Whangai Formation near Coverham, Marlborough. Yet *Rzehakina* has not been recorded from the Seymour Formation (Suggate, 1958) which outcrops further south in the Clarence Valley (e.g. S42/523, F7971; S42/511, F8715; and S41/512, F8244). Again at Amuri Bluff, in the type Haumurian section, a sample from the top Belemnite Bed (S55/506, F9017), 4–6 in. below the contact with the Teredo Limestone has not yielded *Rzehakina*. However, a sample from Kaikoura Peninsula, S49/55, with *Gaudryina healyi* Finlay, *Pseudovalvulineria infrafossa* (Finlay), *Dorothia elongata* Finlay and *Bolivinoides doreeni* Finlay contains specimens of *Rzehakina*. This sample is probably from an horizon equivalent to S55/506. In North Canterbury, S68/194 (F5664), from the upper portion of the Saurian Sands, has a very similar upper Haumurian fauna, but does not contain *Rzehakina*. Recent sampling of the Belemnite bed at Waipara (S68/766, F11267) has given similar negative results. Finally in north-eastern Otago the dark shallow water sediments of the Katiki Formation and basal Abbotsford Mudstone, presently correlated with the Haumurian, show no trace of *Rzehakina*.

In brief, with the exception of the specimen found in S49/55 at Kaikoura, the southern limit of *Rzehakina* in the Haumurian appears to coincide remarkably closely with the distribution of the Whangai Formation which, as Wellman (1955, p. 103) has remarked, changes progressively to the south-east of Coverham to a "sulphurous sandstone with large concretions". Whilst it is perhaps understandable that *Rzehakina* failed to colonise the Seymour Formation, it is enigmatical that the genus does not occur in the topmost Haumurian at Amuri Bluff and more especially Waipara where there is an excellent microfauna. One can only assume that certain environmental conditions inimical to *Rzehakina* but not to many other open water Foraminifera, existed in the area of Haumurian deposition to the south of the Coverham region.

In lower Teurian time *Rzehakina* continued to be almost universally present in areas of Whangai sedimentation and in Northland. In certain closely sampled areas of the Eastern Basin, however, it appears that towards the close of this period, the genus became more restricted in its distribution. This seems well demonstrated in southern Hawke's Bay and Wairarapa. In the Haumurian the genus occurs in a chocolate siltstone (N159/501) lithologically closely similar to the uppermost Teurian Waipawa Black Siltstone (Hornibrook and Harrington, 1957). In upper Teurian time, deposition of dark siltstone became widespread in the Dannevirke Subdivision (Lillie, 1953) and similar types of sediment again occurred in Wairarapa. Restricted faunas occur in these beds with *Bolivinopsis spectabilis* (Grzybowski), *Cyclammina* spp. and *Recurvoides* spp. the most common forms. It is notable that *Rzehakina* does not normally occur in these faunas. It seems reasonable to draw from these relationships that *Rzehakina* in the later Teurian did not occupy environments which it populated in the

Haumurian. At this time, after the extinction of the β form, largest populations of the genus occur principally in fine grained sediments, often bentonitic or associated with bentonites, e.g. F13680, F9709, F13636, F5391. It is an outstanding problem, when considering reasons for the extinction of the genus in New Zealand, that similar fine grained sediments in the Dannevirke Series of the Eastern Basin fail to contain *Rzehakina*. The currently most favoured theory of extinction (Simpson, 1953) is that involving loss of adaptation of groups to their environments; in this case it would appear that some of the environments available in lower Dannevirke time were closely similar, lithologically, to those of the upper Teurian and it is thus difficult to reason what environmental factors were subject to change.

SURVEY OF THE MORPHOLOGICAL CHARACTERS OF *Rzehakina*

It has been described earlier that several morphological groups can be found in many samples containing large numbers of *Rzehakina*. In the lower Haumurian and probably in earlier periods, two forms – α and γ – occur at first both planispirally coiled and distinct largely in terms of prolocular diameter. Under conventional usage these would be termed megalospheric and microspheric generations. In the upper Haumurian, a clearly distinct group (β) appears and becomes widespread. On the evidence of expansion of chambers and the few proloculi measured, it is considered that the group, relative to the α group, is microspheric. Several notable features require emphasis concerning this group. In terms of length and width measurements it has a growth ratio not usually greatly different from the α group although in most samples it is thinner than α forms due to lesser inflation of the chambers. Coiling is quite different to the α pattern although in the Teurian the γ group, due to rotation of the planes of coiling of early chambers, comes to approximate it.

The relations of the β group are difficult to ascertain. No ancestors have been discovered, a fact which points to the probability that it represents either the microspheric form of a new line or a new generational group arising from, and closely related to, the α and γ groups. Considering the first possibility, attention must be drawn to the occurrence of the δ group in several Northland and in one Eastern Basin sample; this group appears megalospheric and, apart from the much greater rate of expansion of chambers, clearly tends to approximate the β group in its pattern of coiling. Yet if β and δ are assumed to be megalospheric and microspheric generations of a genetic group distinct from α and γ the great rarity of δ poses a problem. Large numbers of β specimens occur in many Eastern Basin samples yet only one δ specimen has been found; neither is δ to be found widespread in Northland. In the present state of knowledge it seems preferable to subscribe to the second argument, namely, that the β and δ groups are generational forms belonging to the α and γ stock. This belief is supported by the similar growth forms of the α group and the β group and particularly by the prevalent occurrence of the several groups in association. It is exceptional to find samples in which the β group alone represents the genus.

At this stage consideration must be given to the position of *Silicosigmoilina* Cushman and Church 1929. These authors (1929, p. 502) gave this description: "Test in the early stages nearly planispiral, later becoming sigmoid; wall finely arenaceous with siliceous cement; aperture at the end of the tubular chamber without apertural teeth. This genus strongly resembles *Sigmoilina* in the calcareous imperforate group. *Sigmoilina* has calcareous cement even though the wall is, in some species, encrusted with arenaceous material, and is divided into definite chambers and the aperture typically has a simple linear tooth". However, as Israelsky (1951) remarks when discussing the genotype *Silicosigmoilina california* Cushman and Church, "only beyond the first two chambers can the structure be termed planispiral". The pattern of coiling is thus basically that seen in the local β and δ groups, and as apertural features and wall structure are similar these forms could be referred to *Silicosigmoilina.* The essential difference in the diagnoses of *Rzehakina* Cushman and *Silicosigmoilina* Cushman and Church as they stand at present is that while the former is planispirally coiled, the latter shows progressive rotation of the planes of coiling of the early chambers, finally becoming planispiral. Now in New Zealand it can be shown that the γ form, microspheric in respect to the megalospheric α group, is wholly planispirally coiled in the Haumurian whereas some upper Haumurian and the Teurian populations show rotation of planes of coiling of the inner chambers. For this reason it is considered that the geometry of early chambers may be an unreliable criterion in generic classification of the Rzehakinidae. The association of wholly planispiral forms and those showing rotation of planes of coiling of early chambers appears not to be limited to New Zealand. A sample collected by J. M. Dorreen, and now in collections of the New Zealand Geological Survey, from surface outcrops of the Paleocene Mal Paso Shale, seacliffs south of Paita, N.W. Peru, has planispirally coiled specimens closely similar to the α group of this study together with forms showing coiling and shape features identical with the local β group. Neither of these forms are recorded by Frizzell (1943) in his study of the Mal Paso microfauna from subsurface samples. A Californian upper Cretaceous sample from the Panoche Formation of Los Banos Creek, Merced County, supplied in 1940 by the Superior Oil Company to the New Zealand Geological Survey has large inflated individuals with coiling and rapid expansion of chambers more similar to the local δ group than the β group. Together with these occur simple planispirally coiled specimens of the α type. It appears from Mallory's recently published (1959) review of the microfaunas of the Californian lower Tertiary that both of these forms are referred to *Silicosigmoilina:* for example, compare Figs. 10b and 11b of Plate 5 of Mallory (1959): both are assigned to *Silicosigmoilina california* Cushman and Church yet the specimen drawn in Fig. 11b is clearly planispiral. The Californian form listed as *Spiroloculina*? cf. *lamposa* Hussey by Mallory (1959), Smith (1957), and Graham and Classen (1955) is quite probably linked with the Rzehakinidae judging from illustrations. Smith (1957) points out that the specimen figured by her (Pl. 19, Fig. 11a, b, c) shows a quinqueloculine stage. It is unfortunate that none of these authors discuss the wall structure of this species. The validity of *Silicosigmoilina* Cushman and Church must eventually be determined by careful study of the Californian faunas. It is clear that in this country the microspheric (γ group) of *Rzehakina* does show rotation of planes of coiling in upper Haumurian and Teurian populations; this being so, it would be quite unrealistic to assign the β and δ groups to *Silicosigmoilina.*

It has been already stated that at present all four forms, α, β, γ, and δ should be considered as generational groups. This is a conservative position based upon the morphological similarities and close sampling association of these groups. It should not at present be taken as support for the scheme of trimorphism put forward by Hofker (1950). The present situation does not approximate Hofker's concept of a primitive holotrimorphic stock leading to progressive reduction of generations, in that the β group appears after the establishment of a simple dimorphic scheme, at least as judged by prolocular dimensions.

One of the prime points of interest arising from the biometric work carried out is the relative stability of form exhibited by the α, β, and γ groups. Apart from the exceptional group occurring in F9073, values for the growth ratio of the α group range from 1·204 for F13636 to 1·483 for F5391 (Fig. 31). Table 3A tests the hypothesis that the α groups of all samples measured in this study come from populations have the same value for *a*, the growth ratio. The technique applied in this Table is discussed by Tippett (1952). It should be noted that the method of analysis of covariance is not strictly valid in this case because the form of growth line used is not the regression line; however, the reduced major axis provides an approximation sufficiently close for the present purpose. The table shows that the hypothesis is to be rejected, the value for the variance ratio exceeding the 1% point. If, however, this hypothesis is set up for the same samples, excluding F9073, there is no cause for rejection (Table 3B). These tests emphasise the low growth ratio found for this last sample; apart from F9073 the values for *a* are clearly closely similiar. Again the β group shows a small range of values. However, Table 3C which lists the test that the γ groups of all samples were drawn from populations with the same growth ratio shows that the hypothesis must be here rejected. Comparison of Figs 31 and 32 gives a visual demonstration of the much greater variability in growth pattern of the γ group compared with the α group. This considerably greater variability of shape in the γ group has been shown in the Eastern Basin to follow a progressive trend from a γ shape essentially similar to the α group in F8633 to more attentuated shapes, with higher values for the growth ratio in Teurian samples such as F3250A and F9709 with other Teurian samples, F5391 and F13636 showing complete segregation of the scatters for α and γ groups. The notable feature when considering Table 3 and Figs 31 and 32 is that shape changes, together with the rotation of planes of coiling, occur in the microspheric group which probably represents the sexual generation (Hofker, 1930, 1950; LeCalvez, 1953) whereas the α and β groups show little variability in shape and even less in pattern of coiling. The α group represents, on analogy with the life cycle of recent Foraminifera, a generation which is the result of asexual process. This relation appears to have been seldom investigated in the Foraminifera and clearly warrants further attention.

In review, the variability so commonly noted by previous workers in *Rzehakina* appears to have been greatly over emphasised and is surely due to the failure to carefully distinguish generational groups. Once this is performed, the variability exhibited appears to be no greater than that shown by other forms.

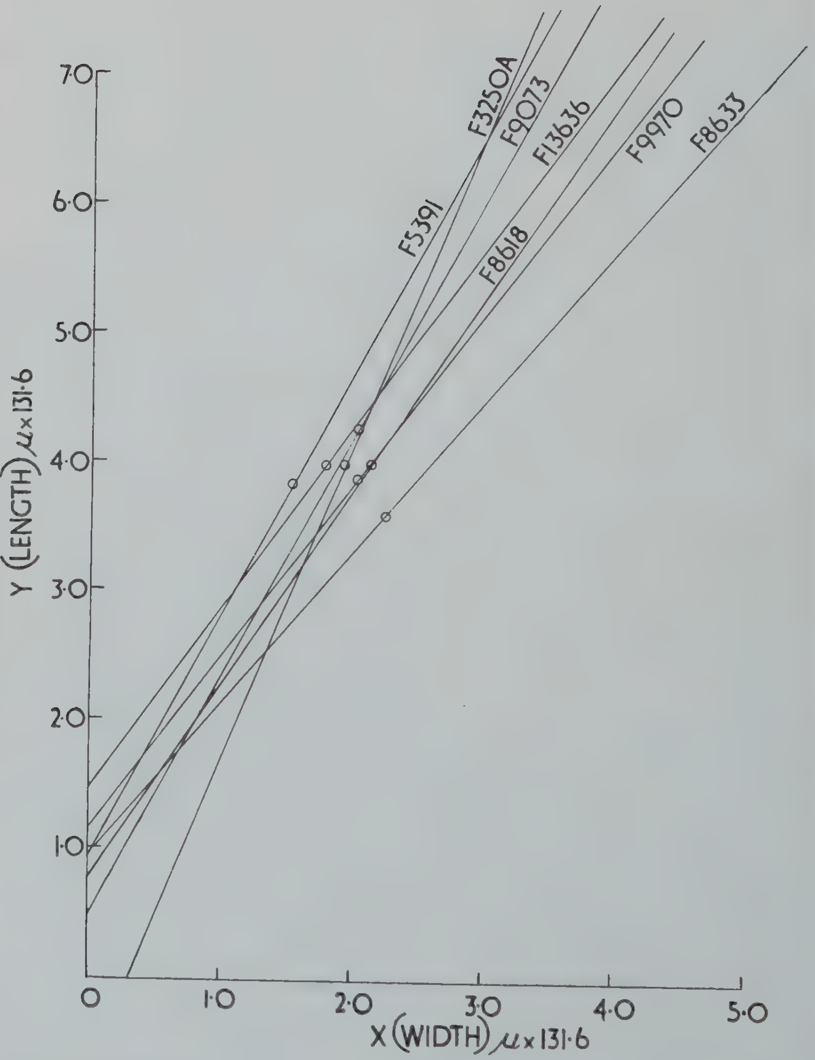

FIG. 32—Reduced major axes for the gamma groups of all samples measured.

OVERSEAS CORRELATION

Rzehakina in this country enters the stratigraphic sequence in the Arowhanan stage currently correlated on the basis of macrofossils with the lower Senonian (Fleming and Wellman in Fleming (Ed.), 1959, p. 32) and ranges up to the Waipawan Stage, placed in the Paleocene by Hornibrook (1958). In terms of Loeblich and Tappan's (1957) reclassification of the Cretaceous-Tertiary boundary, *Rzehakina* in New Zealand ranges into the base of the upper Paleocene (Landenian) as judged by its occurrence in a Northland sample with *Globorotalia* of the *crater* Finlay line, a group very closely allied to *Globorotalia velascoensis* (Cushman) (Hornibrook, 1958). This local range appears to coincide closely with known overseas ranges. In Trinidad, Dr H. M. Bolli (pers. comm.) gives the entry of var. *lata* as the *Globotruncana stuarti* Zone and var. *minima* as the *Globotruncana fornicata Zone*. Bolli (1957) correlated the former zone with the upper Santonian and the latter with the lower Campanian. The upper limit of *Rzehakina* in Trinidad is given as *Globorotalia velascoensis* Zone (upper Paleocene).

TABLE 3—Analysis of variance test for homogeneity of slope values: A—α groups; B—α groups omitting N28/652; C—γ groups

A. Alpha groups, N150/548, N150/547, HT58B, HT45, F3250A, N146/583, F5391, N28/652, N19/545

Source of Variation	Sum of Squares	d.f.	Mean Square
About common line	48.92	359	
About separate lines	46.04	351	0.131
Difference	2.88	8	0.360

$$F_{8,\,351} = \frac{0.360}{0.131} = 2.748 \text{ significant at 1\% level.}$$

B. Alpha groups, excluding N28/652

Source of Variation	Sum of Squares	d.f.	Mean Square
About common line	43.08	333	
About separate lines	41.81	326	0.128
Difference	1.27	7	0.181

$$F_{7,\,326} = \frac{0.181}{0.128} = 1.414 \text{ not significant.}$$

C. Gamma groups, HT58B, HT45, F3250A, F5391, N146/583, F9970, N28/652

Source of Variation	Sum of Squares	d.f.	Mean Square
About common line	21.81	151	
About separate lines	17.73	145	0.122
Difference	4.08	6	0.680

$$F_{6,\,145} = \frac{0.680}{0.122} = 5.574 \text{ significant at 1\% level.}$$

If New Zealand Inocerami correlations and Trinidad microfaunal correlations with the European scale are both reliable, then the genus appears to enter somewhat earlier in New Zealand than in Trinidad. The top ranges in both regions are approximately coincident. In Austria (Dr R. Grill, pers. comm.; and Prey, 1957) the genus enters in the lower Senonian (Zone of *Globotruncana lapparenti lapparenti* Brotzen) and ranges up to the Paleocene (*Globorotalia* horizon), again a range very similar to that in New Zealand. Ranges of the genus in other regions have been summarised by Thalmann (1949). Mallory (1959) puts the upper range of the *Silicosigmoilina california* group as Narizian (upper Eocene) although he notes that it is most characteristic in the Paleocene.

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APPENDIX ON STATISTICAL METHOD APPLIED TO BI-VARIATE ANALYSIS OF *Rzehakina* CUSHMAN (FORAMINIFERA)

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Imbrie (1956) and Kermack (1954) have put forward a method for determining whether growth curves of the type used in Scott's paper are different. This note explains why, although their test for the significance of the difference of the growth ratio (a) has been used, the test of the positional difference has been discarded in favour of an alternative method. The value of the statistic used to test significant differences in position depends noticeably on the particular point at which the comparison is made, and in one case considered ranged from 0·188 (non-significant) to 2·178 (significant) for various values lying within the range of experimental data. There seems to be no obvious reason for preferring, at least in the case of the present paper, any particular point at which the comparison should be made; and if, for example, the point giving the largest value of z is chosen, then some allowance would have to be made for the fact that this had been done, in assessing the level of significance. This would not be easy.

Apart from this objection (which may not necessarily apply in other cases when there is a reason for making the comparison at a particular point) it should be noted that Imbrie's formula (on p. 238) or equation (4) of the present paper is incorrect, and is even more dependent on the point at which the comparison is made than is the correct formula: thus, if $\bar{x}_1$ happens to be nearly equal to $\bar{x}_2$, the variance $y_1 - y_2$ can be made extremely small by making the comparison at a point near the means. This error appears to arise from using Kermack's formula (see Kermack 1954, p. 410).

We have chosen to use instead, a discriminant function to test whether a significant difference occurs between two groups, and then, if the differences are significant, to examine the nature of the discriminant function. The discriminant function has the advantage that it is best not only for distinguishing two chosen groups, but also in predicting to what group an individual belongs. This function for two samples and two characters x and y has the form $l_1x + l_2y$ where l_1 and l_2 are determined by

$$\begin{aligned} l_1\omega_{11} + l_2\omega_{12} &= d_1 \\ l_1\omega_{21} + l_2\omega_{22} &= d_2, \end{aligned}$$

ω_{ij}'s are the elements of the matrix of the estimated values of the co-variance; $d_1 = (\bar{x}_1 - \bar{x}_2)$ $d_2 = (\bar{y}_1 - \bar{y}_2)$, the reader may be referred to Rao (1952) for the method.

To test the overlap of two groups $D^2 = \Sigma\Sigma\omega^{ij}d_id_j = \Sigma\Sigma l_il_j\omega_{ij} = \Sigma l_id_i$; $i, j = 1,2$ is worked out, (ω^{ij}) being the inverse of (ω_{ij}), and Fisher's F test based on 2 and $n_1 + n_2 - 3$ degrees of freedom is used,

$$F(2, n_1 + n_2 - 3) = \frac{n_1\, n_2\, (n_1 + n_2 - 3)}{2(n_1 + n_2)\,(n_1 + n_2 - 2)}\, D^2$$

If the discrimination is due to displacement along the line then the two samples have essentially the same growth form, i.e. for a given x, we expect the same y in both samples; thus the differences are due to somewhat larger specimens of the same type occurring in one sample than in the other: this could be due to sampling effects or age structure of the population. If, however, the displacement of the two groups is primarily at right-angles to the growth curve, it shows that for the same x the two samples have different y's, and consequently are of essentially different shapes.

References are the same as those listed at the end of the paper.

STRATIGRAPHIC NOMENCLATURE OF LATE QUATERNARY PYROCLASTIC DEPOSITS IN NEW ZEALAND

By D. R. GREGG, New Zealand Geological Survey, Department of Scientific and Industrial Research, Christchurch.

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Summary

Stratigraphic nomenclature of unconsolidated pyroclastic deposits (tephra) should conform to the established procedures for other sedimentary rocks. Members should not be established before the formations of which they are part. The geographic part of new rock unit names should preferably not be that of a volcano, except in the case of deposits of historic eruptions. A formation or a member should have a designated single type section. There is no need for the introduction of the term sequence as a formal stratigraphic unit.

Thorarinsson (1953, p. 6) has recently proposed the collective term tephra for all pyroclastic deposits irrespective of grain size. Ash is generally restricted to a grain size less than 4 mm (Wentworth and Williams, 1932, p. 45). Tephra is Greek for ash, and its introduction was favourably received at the 10th General Assembly of the International Union of Geodesy and Geophysics, 1954 (Signore, 1955, pp. 12–14).

Interest in pyroclastic deposits or tephra of late Quaternary age in New Zealand was aroused in the late 1920s when Grange (1937) was geologically mapping the northern part of the Taupo Volcanic Zone. Grange and Taylor (Grange, 1929, 1931; Grange and Taylor, 1932) then started the investigation of soils formed on these deposits. This pedological background explains why the pyroclastic deposits have been treated more as soil parent materials than as litho-stratigraphic or rock units. In pedological papers the custom has grown of referring to both the eruption of the tephra, and the deposit, as a shower; for example, Taylor and Pohlen (1954, p. 21) refer to "the soil formed on the Burrell shower". The first usage is legitimate and useful, and it should be emphasised that the term shower (as in meteorology) refers to an event, and not to the resulting deposits.

The application of radiocarbon dating to late Quaternary stratigraphy has greatly stimulated research on tephra in the Taupo Volcanic Zone, and near Taupo much valuable work has been done by Baumgart and Healy. Baumgart (1954) established the Taupo Ash Sequence, a grouping of the tephra layers near the Terraces Hotel, Taupo. He divided the sequence into 26 numbered members, and named four of them: Taupo Lapilli Member, Rotongaio Ash Member, Hatepe Lapilli Member, and Waimihia Lapilli Member. Baumgart and Healy (1956) renamed the sequence the Taupo Shower Sequence, and named two more of Baumgart's members: Taupo Rhyolite Block Member and the Upper Taupo Pumice Members.

For older rocks, the usage of New Zealand geologists accords closely with the recommendations of the Australian Stratigraphic Code (Australian Committee on Stratigraphic Nomenclature, 1959), although no code has been adopted. In stratigraphic nomenclature tephra should as far as possible be treated like any other sedimentary rocks. It seems to the writer that mappable tephra layers would be better regarded as formations than as members. The formation is the basic rock unit, and a member can only have existence as part of a formation. A member should not be established that is not part of a formation, any more than a group should be established before its component formations. (Australian Committee on Stratigraphic Nomenclature, 1959, p. 65). To formalise the rock units of Baumgart and Healy it would be necessary either to group their named members into formations which may be more or less arbitrary, or to regard their members as formations.

(The American Commission on Stratigraphic Nomenclature (1956, p. 2008) would regard Taupo Lapilli Member, Taupo Rhyolite Block Member, and Upper Taupo Pumice Members as informal names, for they consider that the application of identical geographic names to several minor units in one vertical sequence should always be regarded as informal nomenclature.)

In accepted stratigraphic nomenclature the name of a formation consists of a geographic name coupled with either the term Formation or, preferably, with a lithologic term. Some tephra layers have been given a formational name including the name of a volcano, even when, as in the case of Tongariro Ash, it was very uncertain whether the tephra came from that volcano. Another example is Ngaruhoe Ash, which has originated from all the volcanic vents of Tongariro National Park that have discharged ash since the Taupo pumice eruptions of about 120 A.D. In these cases it would have been preferable to designate a type section (which has seldom been done) and to take the geographic name for the formation from this locality. This was done, for example, in the case of Kaharoa Lapilli. The history of Kaharoa Lapilli as a rock unit was given by Healy (in Fleming, 1959, pp. 150–1), and illustrates the advantages of this procedure. It might be suggested that tephra layers should not be formally named as rock units until their source is identified with certainty. This is impracticable, as many of the older deposits for which formational names have proved useful may not be identified with a definite source, or sources, for many years, if ever.

Few tephra rock units in New Zealand have had type sections designated, and this has led to confusion. In the absence of a definite type section, if any of the correlations published with the original description prove to be wrong, no one can be sure of the significance of the unit. When other ("paratype") occurrences of a formation are included in the original description these should be regarded merely as correlatives of the designated type ("holotype") section. For an old name, proposed without designation of a type section, a subsequent reviser should formally select a type ("lectotype") section from the area mentioned by the original author, and the type section should then be subject to no change.

For a tephra layer that includes a variety of size grades and for which "ash", for example, would not be appropriate as the lithologic part of a formational name, the term tephra may be very useful. The ejecta resulting from the Tarawera eruption of 1886 included both ash and lapilli and may well be termed Tarawera Tephra. For this and similar tephra layers one could speak of the "ash facies" and "lapilli facies" of the Tarawera Tephra, thus using a term that has long proved useful in the stratigraphy of older sedimentary rocks.

The formal naming of a "sequence" as Baumgart (1954) named the Taupo Ash Sequence is a new departure in nomenclature, for New Zealand at least. It is used as a comprehensive grouping of all 26 tephra layers (Baumgart's members). It is not clear whether this unit, the Taupo Ash Sequence, is a rock unit, equivalent in rank to a formation (with 26 members), or some sort of time-stratigraphic unit. The modification of the name to Taupo Shower Sequence, by Baumgart and Healy (1956; see also Healy in Fleming, 1959, pp. 385–6), has emphasised the time aspect, as this essentially refers to a sequence of events. Baumgart and Healy, although establishing Taupo Ash Sequence and Taupo Shower Sequence, have used the units only as headings in their two papers, and not in the texts. The use of sequence as a formal stratigraphic term has been deplored by Moore (1950), and it seems there is no real need for it in nomenclature of tephra layers in New Zealand.

CONCLUSIONS

(1) Pyroclastic deposits or tephra are volcanic sediments and their nomenclature should conform to the established principles of stratigraphic nomenclature.

(2) Members should not be established before the formations of which they are part.

(3) The geographic part of new rock unit names should preferably not be that of a volcano, except in the case of the deposits of historic eruptions.

(4) A formation or a member should have a designated single type section. Other sections should be given as correlatives.

(5) The terms "facies" and "tephra" could useully be introduced into pyroclastic rock nomenclature.

(6) There appears to be no need for the introduction of the term "sequence" as a formal stratigraphic unit.

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MINERALOGY AND ORIGIN OF THE YELLOW-BROWN SANDS AND RELATED SOILS

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(Received for publication, 29 June 1960)

Summary

Soils formed from wind-blown sand are found throughout New Zealand. In order to study their genesis the mineralogy of a large number of these soils from the Manawatu, Waverley, Dargaville, Ruakaka, Ahipara and the Canterbury Plains has been examined.

The Manawatu and Waverley soils were similar in clay mineralogy, the clay minerals being micas, hydrous micas and vermiculite, with traces of halloysite. The pattern of clay content was consistent with the theory that most of the clay in these soils is derived from loess-like material blown in from the beaches after being eroded from older soils in the vicinity. A similar picture was found in a sequence from Dargaville, for the younger soils which were clearly wind-blown and had a clay mineral distribution very like the Manawatu soils. The older soils, however, appeared to be derived from water-deposited rather than wind-blown sand, and contained kaolin and gibbsite, but these also were derived from the sediment and not formed *in situ*. The Ruakaka soils were very similar to the youngest members of the Manawatu soils, except there was a little more kaolin because of the greater prevalence of kaolin in the soils of North Auckland. Although only one site was examined from Houhora in the far north, and so no sequence was possible, the one profile examined could be related to the Dargaville sequence.

The Canterbury Plains soils are derived from sands of river origin as well as marine sands, but the similarity between the soils showed that all these sands must have a common origin. The mineralogy differed from that of the North Island sites in that the dominant clay mineral was clay vermiculite but this was to be expected as this mineral is more prominent in the soils of the hill country from which debris and clay is carried by the rivers.

INTRODUCTION

Soils formed on wind-blown sand are found throughout New Zealand. Most of them are classified as yellow-brown sands by Taylor (1948) but there is considerable variation within the soils of this group. During the general survey of clay minerals in New Zealand (Fieldes, 1957), the yellow-brown sands were not dealt with because of their variability and their generally low clay content. However, as these soils make up 2% of the total area of the soils dealt with in the General Survey of the Soils of the North Island (*N.Z. Soil Bur. Bull.* 5, 1954), it was thought desirable to examine their mineralogy. It was expected that because of variations in parent material, and rapid leaching conditions caused by the excessive drainage characteristic of soils on sand dunes, that some interesting details of the formation of clay minerals would be found in the course of this study.

N.Z. J. Geol. Geophys. 4 : 48–72

SAND-DUNE AREAS

The areas studied in the North Island are shown in Fig. 1. The principal area of soils on wind-blown sand occurs in the Manawatu - West Wellington district, where an almost continuous belt of sand is present along the coast from Paekakariki to Wanganui. This sand varies considerably in composition, containing much more magnetite and ferromagnesians further north and gradually becoming the ironsands characteristic of Taranaki (Oliver, 1948). An important part of this sand country agriculturally is in the Horowhenua-Manawatu area, and this area was studied closely. Isolated patches of sand soils are found along the coast from Wanganui north. Only two of these areas were studied: a sequence on ironsand high in magnetite from Waverley; and a site from the Waikato heads also containing magnetite and other minerals. Large quantities of sand are also found along the western coast of the North Auckland peninsula, from the Manukau Heads north. The greatest extent of these sand dunes and soils is on the coast west of Dargaville and this was one of the areas studied in detail. Another area of sand is found on the east coast near Marsden Point, Whangarei Harbour, which has some points in common with the sand dunes west of Dargaville. A site near Waipapakauri in the far north was taken as representative of a large area of sand country along the North Auckland peninsula north of Kaitaia. In these areas the effect of climate was expected to be far more marked than in the southern areas.

An isolated area of sand near the mouth of the Waipaoa River in the Gisborne district was studied because of the nature of the parent sand. The rocks in the headwaters of this river are all bentonitic and this was expected to have an important bearing on the nature of the mineralogy of the sand. In the South Island, sand dunes are found on the Canterbury Plains on terraces above the river beds and along the coast. The only dunes studied were those around the Waimakariri River.

EXPERIMENTAL PROCEDURE

The air-dried soil samples were treated with hydrogen peroxide to remove organic matter and separated into sand, silt and clay fractions by dispersing in sodium hydroxide at pH 10 and centrifuging. In some cases, iron oxides were removed and determined by the method of Aguilera and Jackson (1953), prior to clay separation; in others, a separate determination of the extractable iron was made. In beach-sand samples where less than 0·1% of clay was expected, clay and silt were removed together and later separated. The sand fractions of some of the soils were sieved to obtain the particle size distribution within the sand fraction.

The clay fractions were examined using X-ray diffraction, differential thermal analysis and electron microscopy. The X-ray equipment used was a Norelco geiger spectrometer. The differential thermal analysis equipment used was that used by Fieldes (1957). Quantitative analysis for kaolin and gibbsite was carried out on this equipment by comparison with standard mixtures. Electron micrographs were obtained by the courtesy of the Director, Dominion Physical Laboratory.

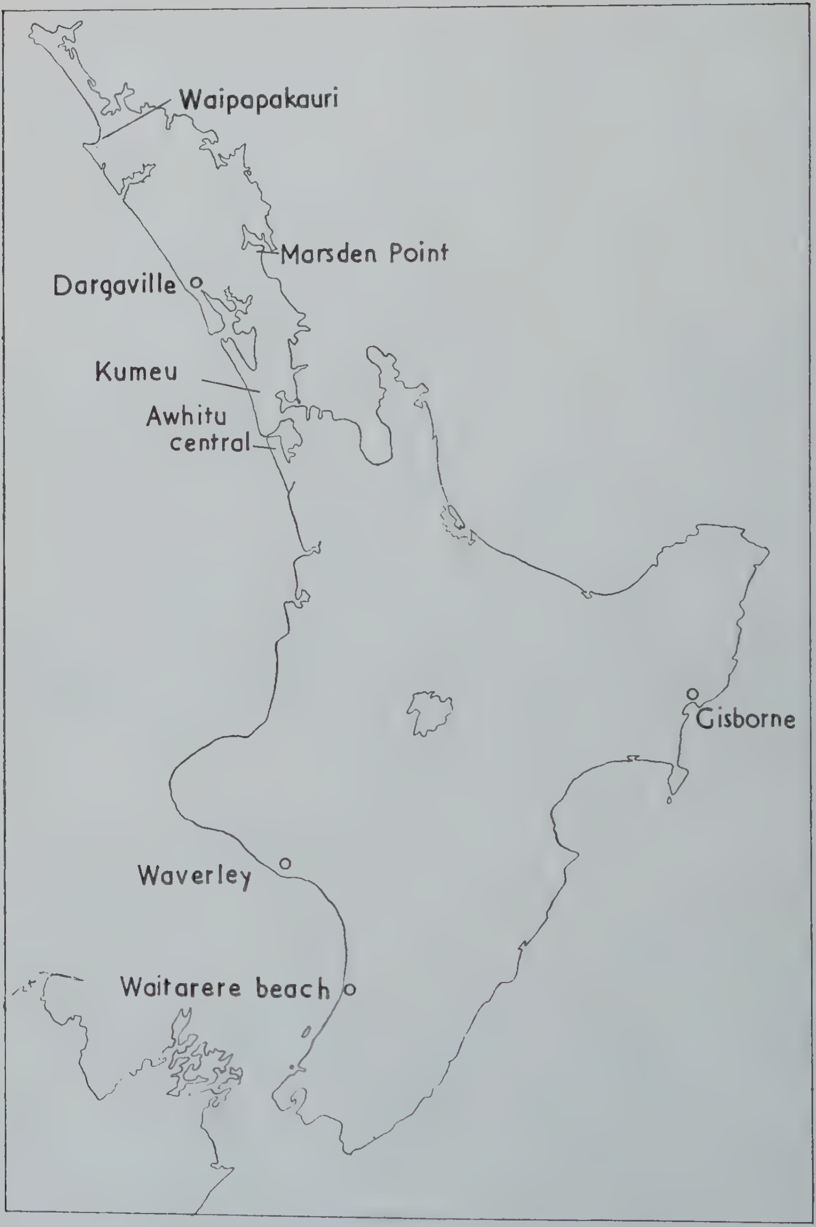

FIG. 1—Map showing sites sampled in the North Island.

The sand and silt fractions were examined by X-ray diffraction. Heavy minerals were separated from some of the sand fractions using bromoform as the heavy liquid and examined with a petrological microscope. Magnetite was separated magnetically.

Sand Soils from the Manawatu

In this region the sand-dune topography is very well developed, four distinct dune-building periods being represented, on which four sequences of soils showing increasing soil development may be recognised. In three of these dune-building periods a very characteristic pattern has been built up. The basic dune form consists of two long almost parallel ridges meeting at their eastern edge and enclosing a gently sloping sand plain. The water table lies well below the surface under the dunes and the higher eastern edge of the sand plains but emerges near the western edge, giving rise to swamps or even to lakes. This pattern has been discussed by Cowie (1957) who also described the soils formed in these drainage sequences. The relationship between the soils of this area can be shown diagrammatically as follows:

Waitarere sand		Hokio sand
Foxton dark grey sand	Himatangi sand	Pukepuke black sand
Foxton black sand	Awahou sandy loam	Carnarvon brown sandy loam
*Koputaroa sandy loam		
Increasing age downwards		Increasingly gleyed across

Waitarere sand is formed on the loose sand dune sands along the coast and represents the youngest soils of the sand country, while Hokio sand is the corresponding soil of the sand plains. Very little weathering of the mineral grains appears to have taken place as the sands are uniformly grey in colour except where they are stained with organic matter. The Waitarere sequence is formed on what is termed by Cowie (1958) the younger dune complex, which has been correlated by Te Punga (1954), with an increase in the amount of sandy debris in the rivers derived from the Taupo ash showers of about 1,700 years ago. The soils of this sequence must therefore be less than 1,700 years old and are thought by Cowie (pers. comm.) to have been stabilised only about fifty years ago.

The Foxton dark grey and Foxton black sequences are formed on an older dune complex which Te Punga places as not older than 3,000 years. The Foxton dark grey sequence is less weathered than the Foxton black sequence as the soils are looser and not so highly stained with iron from the weathering of ferromagnesian minerals in the sand.

Koputaroa sand is the oldest sand in the district derived from sand and is found on isolated remnants of dunes on terraces further inland than the rest of the sand soils. These soils are probably more than 3,000 years old.

Samples Analysed

The samples studied are listed in Table 1 together with the locality from which they are collected. All of the samples studied except Hokio sand came from the Horowhenua district. Samples were collected from Waitarere beach near Levin and from several sites inland from this to cover a range of age and drainage sequences. Hokio sand came from near the coast two and a half miles west of Oroua Downs. However, examination of this sample shows that it was mineralogically comparable with other samples and could be compared with them.

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*Provisional soil name.

Results

The results of particle-size-distribution determinations are shown in Table 1. The two youngest soils investigated – Waitarere sand and Foxton dark grey sand – have similar particle-size distribution and have probably been derived from the same source of sand. Foxton dark grey sand shows a much larger proportion of coarser sand than the Foxton black sand, showing that the sand forming the former dune was coarser than that forming dunes of the Foxton sequences. However, there is very little sand coarser than 350 μ present in any sample.

The amount of clay in the topsoils of these soils, shown in Fig. 2, increases with increasing age of the soil, from 0·1% for raw beach sand to 20% for Koputaroa sandy loam. The clay content increases down the drainage sequence also, the wetter the soil the more clay it contains. In all these

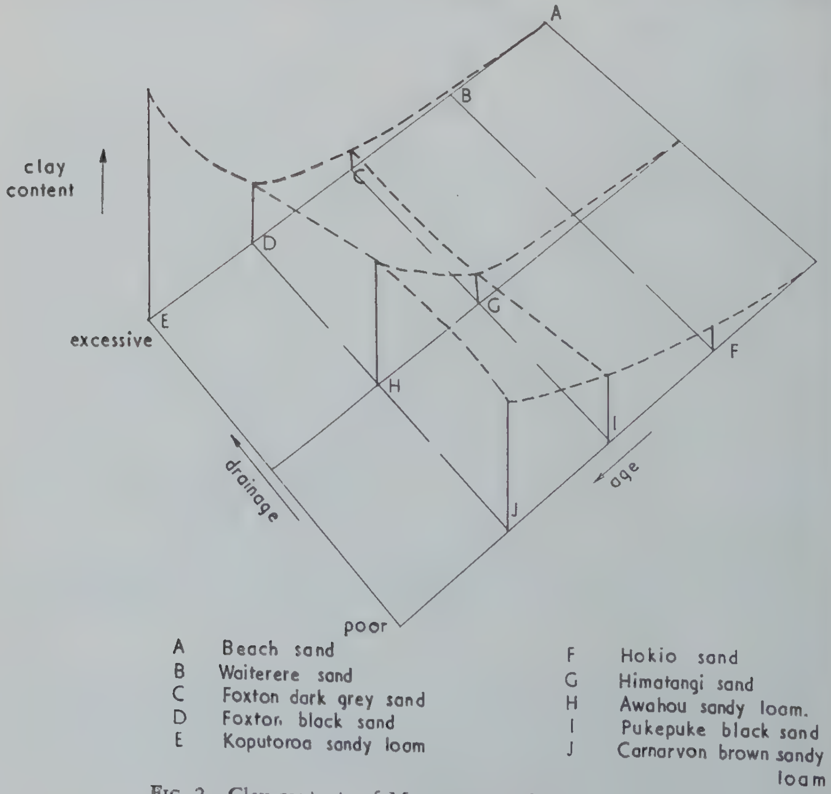

FIG. 2—Clay contents of Manawatu sand country soils.

TABLE 1—Sand Soils from the Manawatu

Sample No.	Depth, in.	Sand				Silt 20–2μ %	Clay <2μ %	Extr. Fe %	Heavy Minerals in Sand Fraction	
		>350μ %	350–150μ %	150–76μ %	76–20μ %				Non-Mag. %	Mag. %
Beach sand, Waitarere beach, between low- and high-tide marks. N152, 717119										
6939 ..	–	(99·75)				0·16	0·09	–		
Waitarere sand, ½ mile south-east of Waitarere Beach. N152, 722113										
6812 ..	0–6	0·6	42·2	55·0	1·2	0·6	0·3	0·24	10·5	0·7
Hokio sand, 2½ miles W. of Oroua Downs. N148, 793339										
6192 ..	0–2	1·0	47·5	42·3	3·3	2·4	3·5	–	13·3	2·2
Foxton dark grey sand, ¾ mile east of Waitarere Beach. N152, 728116										
6813A	0–6	–	36·0	57·0	2·7	2·4	1·6	0·35	8·8	0·8
B	5–12	0·1	32·0	66·0	1·0	0·5	0·5	0·22		
Himatangi sand, 1 mile south-south-east of Waitarere Beach, N152, 735133										
7264A	0–6	(95·4)				2·1	1·9	0·58		
B	8–14	(98·8)				0·3	0·6	0·32		
C	14–20	(99·0)				0·3	0·4	0·34		
Pukepuke black sand, 1 mile east of Waitarere Beach, N152, 734131										
7265A	0–6	(88·0)				6·4	5·0	0·63		
B	8–14	(98·8)				0·4	0·3	0·47		
C	14–20	(99·0)				0·3	0·5	0·19		
Foxton black sand, 2¾ miles north-west of Koputaroa. N152, 813113										
6811A	0–6	–	12·5	59·5	9·5	14·0	4·0	0·53	13·5	1·5
B	14–30	–	23	71	2·4	3·3	1·0	0·33		
C	30–36	0·5	19·5	75·5	2·3	1·1	0·9	0·26		
Awahou sandy loam, Waitarere Beach road. ½ mile from junction with Levin-Wanganui main highway. N152, 775102										
6814A	0–6	0·1	17·2	44·5	14·0	11·8	11·7	0·65		
B	16–21	0·6	35·0	60·0	1·0	2·4	0·9	0·57		
Carnarvon brown sandy loam, Levin-Foxton Rd, ¼ mile S. of Poroutawhoa School. N152, 788111										
6815A	0·6	–	16·4	38·5	17·6	17·6	9·2	0·71		
B	9–15	12·5	16·6	42·0	13·3	5·8	8·0	1·78		
*Koputaroa sandy loam, ¾ mile N.N.W. of Poroutawhao. N152, 846094										
6810A	0·6	–	19·8	29·8	19·8	9·9	19·8	0·96	14·6	1·8
B	9–15	0·1	34·0	38·0	8·5	4·2	13·8	1·37		
C	25–33	0·2	25·4	29·8	13·9	11·9	17·9	1·16		

Figures in brackets refer to the whole sand fraction (>20μ). *Provisional soil name.

soils there is a concentration of clay in the topsoil. The clay content falls considerably not very far below the surface, except in Koputaroa sandy loam where the soil is relatively old, and in Carnarvon brown sandy loam where the lowest horizon sampled is just above the iron pan, through which it was not possible to dig. The extractable iron content of the soils is not high, showing that there has been little weathering, even in the oldest soils. Some of the iron weathered out has gone to stain the sands the characteristic brown colour of the older sand soils, and some has moved down in the drainage water and has been deposited in the subsoil of such soils as Carnarvon and Pukepuke, this being the probable source of iron for the prominent iron pan of the Carnarvon soil.

Microscopic examination of the sand showed that quartz and feldspar together made up about 90% of sand fraction. Mica was present in all sands except that from Koputaroa sandy loam, but in small quantity only. Heavy minerals were separated from some of the sands, and the magnetic fraction removed with a magnet. The magnetic fraction consisted of magnetite, while the non-magnetic fraction was mainly augite, with hornblende and hypersthene. The ferro-magnesians appeared to be quite fresh.

X-ray evidence shows that the dominant clay mineral in these soils is illite, together with partially expanded micas and vermiculites. Differential thermal analyses (Fig. 3) were difficult to interpret because of retained

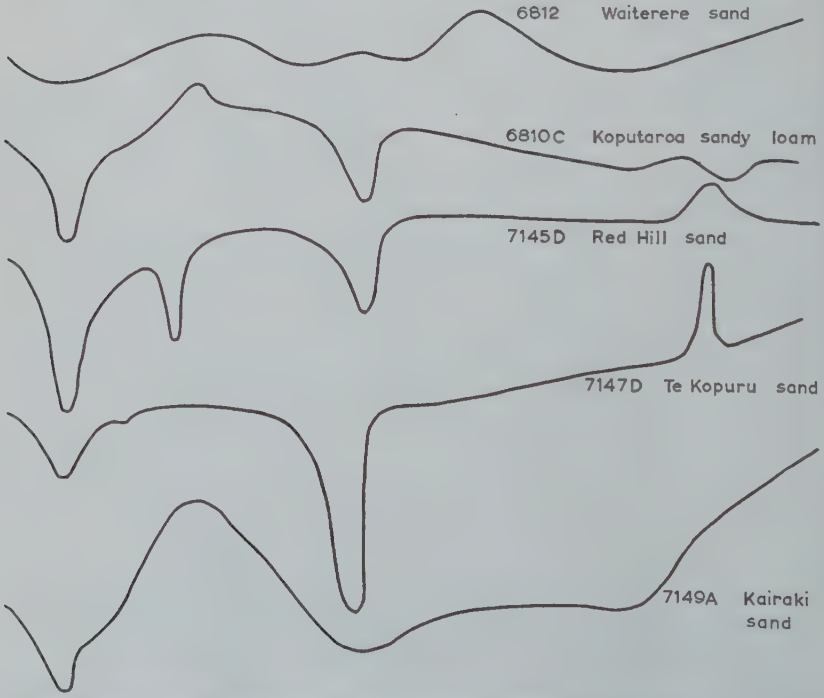

FIG. 3—Characteristic differential thermal analysis patterns of clays from some sand soils.

organic matter, especially in Foxton black sand. It seems characteristc of these soils that the humus is very resistant to peroxide treatment, and in this respect they are very similar to soils on pumice. X-ray patterns of the clays of some of these soils are shown in Fig. 4.

There is an increase in the amount of hydration of the mica, from the youngest to the oldest soil, showing that there is some weathering of the clay minerals themselves. In the soils of medium age (Foxton black sequence) which show retention of organic matter, there is probably some

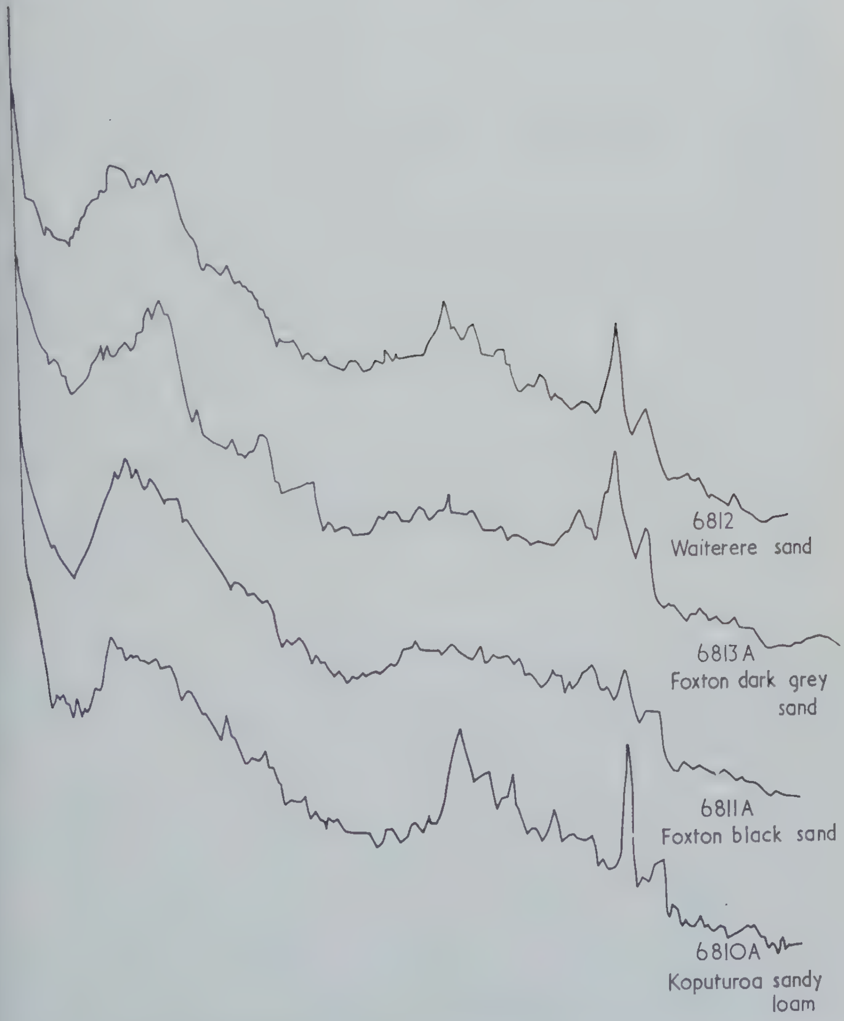

FIG. 4—X-ray diffraction patterns of clay fractions from some Manawatu sands.

clay size hydrated amorphous silica and alumina weathered from quartz or feldspar fragments which has combined with the organic matter in a fashion similar to the younger forms of allophane (Fieldes, 1955).

In the Koputaroa soils, halloysite was also present, the electron micrograph showing this to be in tubular form. Electron micrographs of clays of the other soils show that they contain silica fragments, mica and illite particles and thin vermiculite-like plates, and that clays of the older soils become progressively finer in particle size.

Thermal analysis of the iron concretions in the subsoil of Carnarvon brown sandy loam showed a peak of 230°C which could be attributed to amorphous iron oxides as well as peaks characteristic of micaceous clay minerals. X-ray examination of the iron pan showed only quartz and feldspar patterns, showing that the iron oxides were amorphous. Attempts to separate the clay from the iron pan failed because of the large amount of iron oxides present (at least 25%). These iron oxides cement together sand grains and clay, forming concretions and, in places, a hard pan.

Discussion

The clay mineralogy of the sand soils is somewhat similar to that of the soils in the surrounding district. The soils clearly form an age sequence, in the transition in the clays from coarse micaceous material to the rather finer and more hydrous micas of the Foxton black sand. Since Koputaroa sandy loam occurs only in isolated patches surrounded by soils known to have received contributions from andesitic ash, the presence of small amounts of halloysite may indicate contamination with, in this case, ash material.

There does not appear to be much change in the nature of the clay minerals along the drainage sequences despite the range in conditions from very excessively drained to very poorly drained, and despite the increase in clay content down the drainage sequence. It is therefore postulated that most of the clay content of these soils is derived from wind-blown dust picked up from the beaches. It was found that there is in sand below the high tide mark, a small amount of clay, which would be picked up and carried inland by the prevailing wind. Being lighter, it would be carried much further than sand, and would be deposited over older dunes that were no longer receiving contributions from blown sand. Thus, the older sand dunes would receive more of this fine material than younger dunes, and wetter areas would be expected to retain more of the fine material than the drier dune tops.

This fine material would consist largely of clay and silt derived from the surrounding soils by erosion and carried in suspension by sea water to be deposited on beaches. Its mineralogy would be similar to that of the surrounding soils, which in this vicinity are largely derived from greywacke or Tertiary alluvium. The clay minerals to be expected in these soils are largely micaceous, either illite or hydrous micas being the dominant mineral, together with halloysite in the soils from ash. The micaceous clay minerals are most likely to survive marine transport and would appear on the beaches, together with fine particle size quartz and feldspars formed by the grinding of sand grains. These would therefore become the main clay minerals of the younger sand soils. Alteration by weathering after deposition has resulted in an increase in the hydration of the clay minerals and formation of a little amorphous silica. It is possible that the weathering of fine feldspar grains has released alumina as well and that this has combined with silica to form halloysite, although a more likely explanation seems to be that there has been contamination by andesitic ash in these soils.

The silt fractions are also wind carried, in the same manner as the clay fraction but silt fractions usually show the same mineralogical features as the sand fractions; this was observed in these soils also. The amount of silt increases with age of the soil in the same manner as the amount of clay and for the same reasons.

It could be argued that most of this evidence can be interpreted solely by weathering in the soil as opposed to the postulated wind-blown origin for the clay. There is, for instance, an increase in the clay content in the topsoil with age of the soil which would naturally be interpreted as caused by greater weathering, but if this were so, a breakdown in some of the sand grains should be apparent, which is not shown by examination of the sand fraction. The grains are all fresh and unweathered and only show smoothing due to an abrasion during transport. Koputaroa sandy loam shows an increase in the proportion of coarser sand which could be interpreted as caused by the weathering of the finer particles to form clay. However, since the Koputaroa dunes are all old and are only the residuals of dunes, there has been ample time for the sand to pick up large quantities of fine material; the increase in the amount of coarse material is more likely to be caused by a difference in composition of the original sand forming the dune.

However, the conclusion that a large proportion, if not all, of the clay is of wind-blown origin was confirmed by the study of sand dune soils in other parts of the country, although the dune form was nowhere else as highly developed so that complete age and drainage sequences could not be found.

Sand Soils from Waverley

Three samples of sand and soil from iron sands near Waverley were studied. The iron sand extends from the Manukau Heads to the Wanganui River so that the Waverley dunes are representative of the sands of the southern part of this area. The dunes do not form as regular a dune pattern as that shown by the Manawatu dunes, and samples were taken only from dune soils and not from sand plains.

The dunes from two series – a younger and an older – which were sampled, together with a beach sand. The samples taken and the results of the analyses are shown in Table 2.

The sands are of markedly different composition. Mineralogical examination of the sand shows a very high proportion of magnetite and other heavy minerals: augite, hypersthene and hornblende. Although these minerals are also present in the Manawatu sands, they are present in larger amounts and different proportions. In the Waverley sand, magnetite and ferromagnesians make up most of the sand fraction, while there is a much higher proportion of magnetite than ferromagnesians.

TABLE 2—Sand Soils from Waverley

Sample No.	Depth, in.	Sand				Silt 20–2μ	Clay <2μ	Extr. Fe	Heavy Minerals in Sand Fraction	
		>350μ %	350–150μ %	150–76μ %	76–20μ %	%	%	%	Non-Mag. %	Mag. %
Beach sand, Waverley Beach, N137, 186985										
7235 ..	0–3	(92·3)				4·2	2·6	0·83		
Waverley sand, Waverley Beach, Cliff dune. N137, 187986										
7234A	0–6	2·3	54·1	37·6	1·9	1·4	1·4	1·35	29	46
B	14–20	2·9	60·5	34·3	0·5	0·3	0·6	0·84	36	47
Patea sand, Wairoa Rd, Waverley. N137, 176015										
7236A	0–6	13·8	56·0	17·1	5·4	4·2	2·6	0·83	61	24
B	10–14	13·1	56·5	22·4	2·1	2·5	2·2	0·76	53	31
C	16–24	38·4	55·0	6·0	0·4	0·2	0·3	0·30	68	22

Despite the high proportion of ferromagnesians rich in bases, the clay minerals are still rather poorly ordered micas, with a little kaolin or halloysite showing in differential thermal analysis. Retention of organic matter and increase in hydration is present, but not to such a great extent as in the Manawatu sands.

These results confirm the general theory that the greater part of the clay is derived from nearby sediments. The micaceous minerals would originate in soils from Tertiary mudstones forming the headwaters of most of the rivers of the district, while the halloysite is derived from the yellow-brown loams from andesitic ash on the coastal plains. There is a little amorphous mineral-organic complex derived from weathering of the fine particle size quartz and feldspars. The high proportion of basic minerals has not had any great effect on the nature of the clay minerals.

Sand Soils from Dargaville

A large belt of sand dunes extends from Anawhata, just north of the Manukau Harbour, to north of the Kaipara harbour and in patches to the Ninety-mile Beach. The region studied in detail lies west of Dargaville, but the soil and sand pattern is typical of most of the area. The main soils of this region are:

(1) Pinaki sand -- a very young soil formed on very recent sand dunes;
(2) The Red Hill soils – sands formed on older sand dunes, but the dune pattern still shows:
(3) Tangitiki and Te Kopuru soils – soils formed on slightly consolidated sandstones of late Pliocene or early Pleistocene age.

These soils can be correlated with the geology of the region. According to Brothers (1954), the region between the South Kaipara head and the Waitakere ranges consists of a thick deposit of horizontally bedded and massive sandstones, pumice silts and muds with interbedded dune sands and lignites. The whole formation (Kaihu formation) is considered to be of late Pliocene or early Pleistocene age and is known from south of the Manukau harbour to the Ninety-mile Beach.

Near the coast low terraces cut in this formation have been covered with wind-blown sand and still have the irregular sand-dune topography. Brothers terms this the South Head formation and gives it a mid-Pleistocene age correlating it with a lowering of sea-level during the penultimate glaciation. Recently, sand has started to blow inland again and a coastal strip of shifting sand is at present being formed.

Pinaki soils are found on the youngest dunes and have all the characteristics of young yellow-brown sands. The soil is very shallow – a few inches of humus stained sand, held together by a mat of roots with a small amount of clay, followed by brown unconsolidated sand.

The Red Hill sands lie inland from the Pinaki sands and, although showing irregular dune topography, the dunes are more subdued than the Pinaki dunes and obviously much older. The Red Hill soils are mapped as being formed on the South Head formation of Brothers, near Kaipara South Head and are formed on similar formations in other places. A typical Red Hill profile consists of several inches of dark brown sand with a sharp boundary to a brown sandy clay loam, which gradually becomes more compact and grades to a red sandy clay, sometimes containing white nodules, on slightly consolidated sands.

Poorly drained hollows are found amongst Red Hill sands, as in most dune areas, and peats and peaty sands are found in these hollows. One profile on the edge of a peaty hollow consists of about 7 in. of greyish brown sandy topsoil on 6 in. of white weakly consolidated sand (the A_2 layer of a ground water podzol), below which is about 8 in. of dark brown sand on a weakly cemented pan about 3 in. thick.

Inland from the Red Hill sands, the underlying Kaihu formation comes to the surface. This is rather variable, consisting mainly of water deposited sands with old dune sands, lignites, pumice, etc., interbedded, and probably has rather a mixed history. There are two soils formed in this area: Tangitiki, a strongly leached sandy yellow-brown earth; and Te Kopuru, a sandy podzol. These grade into each other, although in general the Tangitiki soils are found on the slopes and Te Kopuru on the ridge tops and plateaux. The Te Kopuru podzol is one of the more spectacular podzols of North Auckland. A typical profile consists of 8–10 in. of dark grey sand on a greyish white silica sand pan about 10 in. thick, which is strongly indurated and massive. Below this is an indurated humus and iron pan about 8–9 in. thick and reddish brown to black in colour, on pale brownish yellow sandy clay, grading into looser sands below. The Tangitiki soil, on the other hand, consists of several inches of dark grey sand on yellowish brown to brown sand and sandy clay grading down into slightly consolidated sands similar to those below the Te Kopuru profile. The difference between these two soils is related to the vegetation pattern as well as to slope.

Relationship of Sands in the Dargaville Area

Soil type		Geological formation
Beach Sand		recent dunes
Sand		
Pinaki Sand		
Red Hill Sands		South Head Formation
Te Kopuru Sands	Tangitiki Sands	Kaihu formation

Samples

Samples were collected from all these soils as well as one from a recent sand drift as shown in Table 3. The Tangitiki and Te Kopuru profiles were later resampled – Te Kopuru profile being found close to the original Tangitiki site, and a Tangitiki close to the original Te Kopuru site. These samples were analysed, using the usual methods and the results are also quoted in Table 3.

The particle-size distribution figures show that the younger sands are slightly coarser in texture than the Manawatu sands, but there is a rapid increase in the amount of clay in the older sands.

There is little difference in clay mineralogy between the beach sand, and Pinaki sand, although there are differences in the amount of fine sand and heavy minerals. The clay fractions of these soils contained quartz, feldspars and partially hydrated micas, i.e. the glycerol treated samples gave a number of peaks between 10 and 14 Å. Pinaki sand also contained a little kaolin.

The Red Hill sand is considerably older, as is shown by the clay content and extractable iron figures. This profile shows evidence either of clay shift or of a break in the profile at about 10 in. Other evidence for this break is that although no gibbsite was found in the upper parts of the profile, in a cutting not far from the profile site, gibbsite nodules were found at a depth of from four to five feet.

The clay fraction of the Red Hill profile was similar to Pinaki sand in composition, but the lowest horizon contained considerable gibbsite, which agrees with the presence of discrete gibbsite nodules at this level.

The Tangitiki profile is clearly similar to the Red Hill in clay content and particle size distribution, and appears to have undergone a similar type of weathering. The micas are now fully expanded to 14Å in the upper part of the profile, and there is considerable kaolin present – up to 75% of the total clay fraction in the lowest part of the profile. There is also some gibbsite present up to 20% in one horizon.

The Te Kopuru profile shows all the features of a podzol: clay shift down the profile, iron movement and a cemented silica sand pan. The minerals of the clay fraction of the bleached layer are quartz, feldspar and micaceous minerals, without any kaolin; below the pan, large amounts of kaolin are present. No trace of gibbsite was observed in this profile. In Fig. 5 the X-ray diffraction patterns of the horizons of this profile are shown.

In order to determine whether the absence of gibbsite was caused by the podzolising process, further sites were sampled. As the Tangitiki and Te Kopuru soils form a complex, it was possible to find a Tangitiki soil within half a mile of the Te Kopuru profile originally sampled, and a Te Kopuru

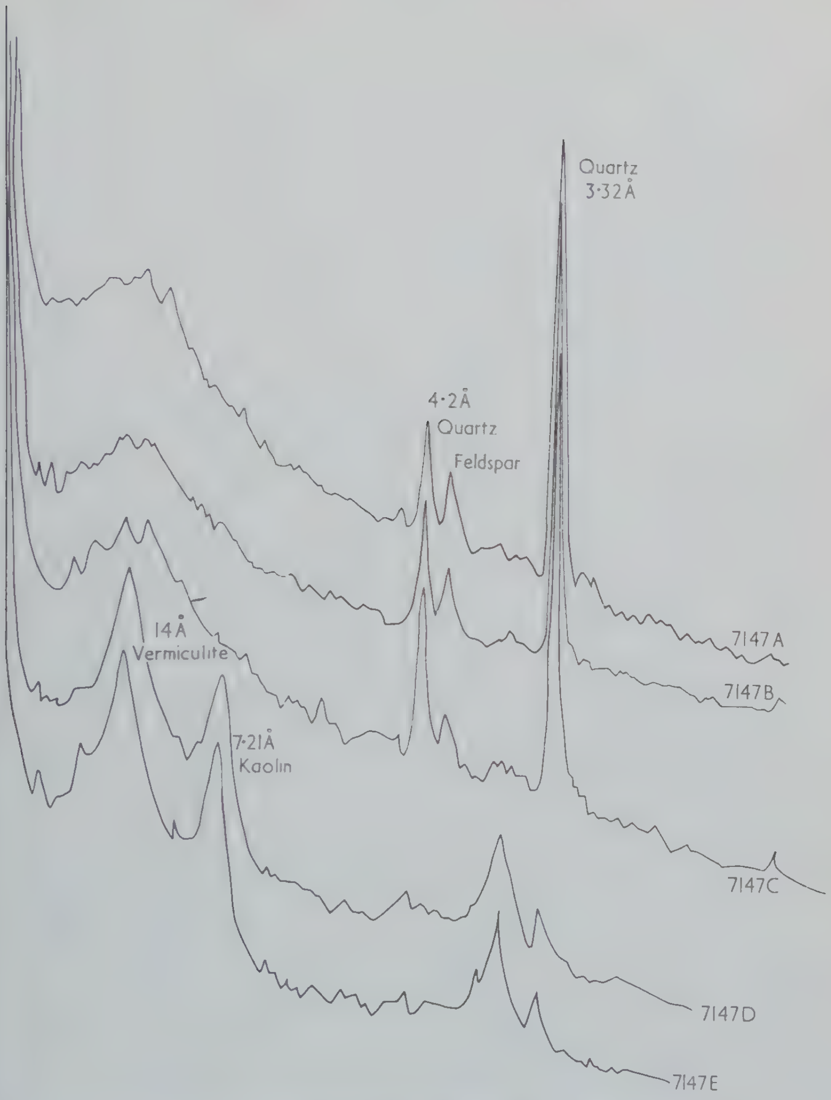

FIG. 5—X-ray diffraction patterns of clay fractions from Te Kopuru sand.

close to the Tangitiki profile originally sampled. Analysis showed that the second Tangitiki profile contained kaolin but very little gibbsite, whereas the second Te Kopuru profile contained gibbsite in the lower horizons. From these analyses it appears that gibbsite is present in some of the beds of the Kaihu sandstone and not in others, but is not forming in the soil at present.

TABLE 3—Sand Soils from Dargaville

Sample No.	Depth, in.	Sand				Silt 20–2 µ %	Clay < 2 µ %	Extr. Fe %	Heavy Minerals in Sand Fraction		Clay Fraction	
		> 350 µ %	350–150 µ %	150–76 µ %	76–20 µ %				Non-Mag. %	Mag. %	Kl %	Gb %
Beach sand, Hardings Rd, Mahuta. N23, 333613												
7143 ..	0–36	0·23	71·1	26·9	0·4	0·2	0·9	0·23	2·5	0·02		
Pinaki sand, Rehutai Rd, Dargaville. N23, 302650												
7144A ..	0–5	–	53·2	40·3	4·1	1·3	0·7	0·40	13·5	0·5		
C ..	10–20	0·1	52·8	44·8	1·0	0·4	0·6	0·25				
Red Hill sand, Baylys Coast Rd, Dargaville. N23, 288684												
7145A ..	0–5	1·7	26·6	33·2	12·8	14·1	10·4	1·26	4·1	0·3		
B ..	5–10		(64·4)			15·4	15·8	4·36				
C ..	10–20		(71·4)			3·3	21·7	3·75				
D ..	20–36	3·3	48·3	15·9	2·4	4·9	24·3	0·93				
E ..	42+	10·8	62·2	19·7	1·0	2·1	3·2	0·95	7·6	0·4		
Peaty Hollow in Red Hill sand, ½ mile N. of 7145												
PC250 ..	6–12		(78·7)			17·5	3·7	0·10				
PC251 ..	12–24		(83·2)			8·9	6·9	0·96				
Tangitiki sand, Hardings Rd, Mahuta. N23, 386673												
7146A ..	0–5	75	51·9	15·1	5·7	10·9	6·0	2·84	0·7	–	7	2
B ..	6–12		(71·6)			9·7	14·0	4·60				
C ..	14–26	4·8	39·7	13·9	6·3	10·0	22·6	1·60			12	20
D ..	34–44		(71·2)			8·5	19·7	0·60				
E ..	96+	4·2	37·6	26·3	14·0	8·2	9·7	0·09	0·1	–	75	1

Tangitiki sand, Hokianga Rd, 1 mile N. of 7147													
PC256	..	18–21	(69·5)				9·7	19·6	1·16				
PC257	..	24–31	(57·5)				7·8	34·0	0·72			50	2
PC258	..	60+	(66·0)				13·8	19·8	0·42			60	–
Te Kopuru sand, Hokianga Rd, Dargaville. N23, 377715													
7147A	..	0–8	–	12·3	48·2	24·2	12·9	1·6	0·82	0·1	–	–	
B	..	8–18	–	16·1	46·6	19·4	17·8	0·1	0·01			–	
C	..	18–27	–	18–7	45·6	17·6	13·9	4·2	0·01			–	
D	..	27–37	–	7·0	17·7	6·6	9·6	58·2	0·82			56	
E	..	37–65	2·0	4·9	13·5	6·3	8·6	62·1	2·60			77	
F	..	60+	–	20·5	40·2	4·5	8·2	25·8	0·78	0·1	–	60	
Te Kopuru sand, Hardings Rd, Mahuta, ½ mile W. of 7146													
PC252	..	7–12	(76·2)				13·6	10·0	0·17			56	
PC253	..	24–36										90	
PC254	..	60+	(67·8)				8·8	21·1	2·25			30	14

That considerable mineral weathering has taken place is borne out by mineralogical examination of the sand fractions. In the beach sand and Pinaki sand, the mineral grains are rounded and show no signs of decomposition. The heavy minerals are mainly augite and hornblendes, with some magnetite. The surface horizon of Red Hill is similar in appearance to Pinaki, but contains less heavy minerals. In the lower horizon, the augites show marked signs of decomposition and this could be taken as evidence of a break in the sequence with a greater degree of weathering at depth.

The Tangitiki and Te Kopuru soils contain only a very small proportion of heavy minerals, probably caused by the disappearance of much of the less stable ferromagnesians during the sand's history, and, as a consequence of this, more zircons and apatites are visible. Ferromagnesians show signs of marked decomposition in the Tangitiki profile, and are rare in the Te Kopuru profile. The light fraction of the sands was made up of quartz and feldspars.

Origin of soils

The youngest soil, Pinaki, is obviously of aeolian origin and the clay minerals are consistent with the theory that these are mainly derived from loess-like material. The presence of kaolin in these clays is not unexpected as kaolin is a common constituent of many of the soils of North Auckland, and would be expected to be amongst those minerals carried in suspension in sea water. The Red Hill sand appears to be derived from sand of similar origin to the other soils as shown by its particle size distribution, but it has been subject to considerable weathering in the past, as shown by the presence of gibbsite in the lowest horizon and the presence of nodules. The gibbsite may, however, have been present in the original sand. It is possible that this profile is a two-story one, with the lower portion being weathered since the mid-Pleistocene, when according to Brothers (1954) these sands were deposited. They were then covered by a later but still old mantle of sand which has not weathered so much; and the clay mineral content is in large part derived from wind-blown material.

The Tangitiki and Te Kopuru soils are formed not on true windblown sands but on loosely consolidated sandstones, probably of estuarine origin, although there are some blown sands included in the sequence. These sands have been subjected to considerable weathering as shown by the decomposition of the sand grains and the formation of large amounts of kaolin in the soil. Because of the permeable nature of the sands and the relatively small amount of clay minerals contained in them, the effect of the podzolisation process is very marked. The Tangitiki soils were formed under a mildly podzolising podocarp forest but where the vegetation changed to the very strongly podzolising kauri forest, the strongly podzolised Te Kopuru soils are found. These soils grade into each other and form an intricate pattern related to the vegetation pattern. Tangitiki soils show some shift in clay and iron oxides showing that these soils are weakly podzolised although quite strongly weathered.

It is difficult to determine whether kaolin is forming in the present day soils or whether it is derived from the parent material. The proportion of kaolin in the clay fraction increases with depth in these soils and if it were forming in the soil it would be expected to be larger in amount in the upper horizons where weathering is greater. The distribution of gibbsite has been shown to be a parent material effect in the Tangitiki and Te Kopuru soils and gibbsite is not forming to any extent under the present environment.

Sand Soils from Marsden Point

South of Whangarei harbour, extending from Marsden Point to Ruakaka, are a set of recent sand dunes with a sequence of two soils. The youngest soil is Marsden sand, a very young soil on recent sand dunes, with peaty sands and peats in the hollows (Marsden complex (peaty sand)). Further inland is an older set of dunes, over slightly consolidated sandstone, which resembles those on the west coast. The soils on these sands are named Red Hill sands on analogy with the west coast sands of the same name. In addition, there is a small area of soil at One Tree Point, a few miles to the west of Marsden Point, formed on a peaty sandstone. This profile consists of a black peaty sand on a consolidated, humus-stained massive sandstone. (One Tree Point peaty sand.)

Samples

Samples of these soils (as well as from a beach sand) were collected from the sites quoted in Table 4 and analysed. The results of these analyses are also quoted in the table.

Results

The clay content increases from 0·1% for the beach sand to 4% for the Red Hill sand. The lower clay content of the top six inches of the Red Hill sand is probably the result of a recent accumulation of sand and the 6–12 in. horizon is probably a better approximation to the topsoil of this profile. There is considerable clay accumulation in the topsoil of the peaty phase of Marsden sand as would be expected if the wetter areas were trapping more clay blown across by the wind.

The extractable iron figures are normal, low in Marsden sand but higher in the horizons of Red Hill sand containing more clay. Very little iron is found in the peaty phase of Marsden sand, probably because of the lack of oxidising conditions to cause weathered iron oxides to be deposited as ferric oxides.

The sand size fractions vary somewhat in composition, ranging from two to twenty per cent of heavy minerals, but the mineralogy of each density fraction is similar. The light fraction consists of quartz and feldspar, and the heavy fractions of augites, decomposing and full of dark inclusions, but well rounded and of opaque minerals not identified. There is only a trace of magnetic material, even in the samples with a high heavy mineral content. The reason for the high content of ferromagnesians in the Marsden sand is not known.

The dominant clay mineral is micaceous in nature, either a hydrous or partially expanded mica, or else a completely expanded vermiculite. A little kaolin is present, as well as clay size quartz and feldspar. The sands of this area appear to follow the same pattern as those of the Manawatu sand country. Two groups of soils can be distinguished and the clay mineralogy of these soils and the beach sand associated with them are all similar. Once again, the clays are derived largely from loess-like material blown in from the sea and with very small contributions from mineral weathering. The decomposition of the ferromagnesians has in this case probably taken place during the breakdown of the rock to form sand, the absence of magnetite showing that the sands have a different origin from the west coast sands.

One Tree Point Peaty Sand

The profile of One Tree Point peaty sand, which covers a small area of the west of Marsden Point, was studied. Where examined the soil profile consists of about 6 in. of loose peaty sand on a black to dark red cemented massive sandstone which is supposed to be the B horizon of a very old ground water podzol. In places the A_1 horizon has long since eroded off and has supplied the debris to form the Marsden dunes, and the soil is formed on the cemented B horizon (N. H. Taylor, pers. comm.). The clay content is comparatively high in the profile but the extractable iron content is low. Sand minerals are very similar to those of the Marsden sands, except that there is perhaps a little more magnetite. The clay minerals are similar to the other soils except for a trace of cristobalite.

Although these sands are similar to the Marsden sands, they have had a more complicated history. The actual soil is formed by loosening of the surface of the consolidated sandstone and some blowing about of the sand. The consolidated sandstone already contains clay, which like that in the Te Kopuru profile, is mainly poorly oriented micas, but during the process of soil formation the micas have recrystallised sufficiently to enable their identification as hydrous micas.

Other Sand Soils of the Auckland Province

Samples were available from other areas containing sand soils, and were also studied although only one site was sampled in each case.

Houhora Sand

Houhora sand forms a long coastal strip inland from the Ninety-mile Beach. It is formed on deep weathered sands or sandstones, slightly consolidated. It is probable that these sands are of the same age and nature as those of the South Head formation referred to above. One profile was sampled from near Waipapakauri; samples were collected down to eight feet to characterise the profile, and the results are listed in Table 4.

The proportion of heavy minerals in the sand is very low. Only a trace of magnetite was present. The heavy minerals present are mainly augite with some hornblende.

The clay minerals present are vermiculite, gibbsite and kaolin. There is only a small amount of kaolin present, about five per cent, and about twenty per cent of gibbsite, the rest being vermiculite and clay size quartz and feldspar. There seems to be little differentiation throughout the profile, but the deepest sample (7240G) which was collected a short distance from the other samples in a road cutting, is very different. This contains about 60% kaolin and an unexpanded mica, instead of 14Å vermiculite found in the other samples of the profile.

TABLE 4—Sand Soils from Marsden Point, and Other Areas in the Auckland Province

Sample No.	Depth, in.	Sand >20μ %	Silt 20–2μ %	Clay <2μ %	Extr. Fe %	Heavy Minerals in Sand Fraction Non-Mag. %	Mag. %
Beach sand, Marsden Point. N24, 010835							
7276	0–18	99·5	6·2	0·1	–	2	–
Marsden sand, 2 miles south of Marsden Point. N24, 975798							
7277A	0–3	97·6	1·0	0·8	0·43	22	tr.
B	6–14	99·0	0·4	0·3	0·35		
Peaty phase of Marsden sand, near 7277. N24, 975798							
7278A	1–6	76·2	18·2	5·6	0·05	13·1	tr.
B	10–20	99·2	0·3	0·5	0·03		
Red Hill sand, Takahiwai Rd, Marsden Point. N24, 972813							
7279A	1–3	96·2	1·7	1·5	0·56	3·5	–
B	9–14	93·2	1·1	4·0	1·68		
C	48–75	99·5	0·3	0·2	0·07	7·9	tr.
One Tree Point peaty sand, One Tree Point. N24, 967857							
7275A	0–6	81·4	16·0	2·4	0·14	7·7	–
B	7–12	86·2	7·8	5·8	0·10		
C	36–42	96·3	1·6	2·1	0·01	3·7	tr.
Houhora sand, Waipapakauri – Ninety-mile Beach Rd. N9, 714799							
7240A	0–3	83·0	8·2	7·3	1·46	1·8	–
B	3–6	82·4	11·4	4·3	2·08		
C	7–11	82·4	8·4	8·3	1·30	0·7	tr.
D	11–20	80·8	8·0	9·8	1·37		
E	20–31	84·9	8·0	5·4	1·73		
F	40–46	87·2	6·3	5·2	1·38	0·5	–
G	180	90·8	3·6	4·7	0·91	0·5	–
Red Hill clay loam, Awhitu Central, Franklin County							
1240A	0–4	43	8·5	43	5·75	20	13·0
B	6–12	34·0	6·5	52·7	7·35		
Red Hill sandy clay, Kumeu							
800	0–5	50	28·5	20	1·50	2·4	
801	9–13	56	10·5	31	2·6		

The extractable iron content is fairly high for a sand, showing that some weathering of the mineral grains has taken place. The uniformity in texture of this profile appears to indicate that very little mineral weathering and clay formation has gone on since the sands were laid down as the upper horizons would be more weathered than the lower if much weathering of the soil had taken place on the site. The clay content is therefore probably derived from a previous cycle of weathering before the sands were deposited. This would also offer an explanation for the difference in mineralogy between sample 7240G and the rest of the profile.

Other Red Hill Soils

Samples were available from two sites on the west coast, and these were examined, the results being shown in Table 4. Red Hill clay loam from Awhitu Central, near the Manukau South Head, is on a sand high in magnetite and other heavy minerals as would be expected from a site in this region. This site is near the northern end of the iron sand range. Halloysite is found amongst the clay minerals, but this could have been derived from a topdressing of ash, as the soils further inland are derived from Hamilton ash. The other clay minerals are illite and quartz.

Red Hill sandy clay from Kumeu is similar to the Red Hill soils further north around Dargaville which were discussed above, except that there is a large amount of halloysite visible in the electron micrograph of this sample, which was not seen in the samples from near Dargaville. It would appear from this that the sand from which this soil is derived has had a considerable contribution from ash. A few shards of glass were observed in the sand fractions which would confirm this hypothesis.

Sand Soils from Gisborne

In order to check the hypothesis that most of the clay in a young sand soil is derived from wind-blown dust and not from weathering taking place in the soil, two profiles of Opoutama sand from Gisborne were examined. The principal source of debris for the beaches is the Waipaoa River, and the alluvium carried by this river contains large amounts of montmorillonite (Claridge, 1960). It would therefore be expected that montmorillonite would be found in these soils. In the four samples studied, the clay minerals found were montmorillonite and micaceous minerals of varying degrees of hydration. This is what would be expected from a knowledge of the clay mineralogy of the sediments, except that more montmorillonite would be expected.

The sand itself contains about 5% of heavy minerals, such as augite and hornblende, some very slightly decomposed, and about 1% of magnetite. The rest of the sand consists of quartz and feldspars, with opaque aggregates that could be broken under pressure, and probably consisting of harder fragments of the argillites that make up much of the hill country. The heavy minerals and some of the quartz and feldspars are probably derived from the mantle of rhyolite ash that covers this district.

Sand Soils from the Canterbury Plains

On terraces bordering the rivers of Canterbury and along the coast are sand dunes, the sand bordering the rivers being blown out of the wide river beds by the prevailing north-west winds. On the plains there are a series of terraces which have been related to stages in the glacial era (W. T. Ward, pers. comm.), and the dunes found on the edges of these terraces must be younger than the terrace itself. Three sets of terraces are known, and the soils on the two youngest of these were sampled. These were Paparua loamy sand, on the intermediate terrace, correlated by Suggate (1958) with the Blackwater glaciation of Gage (1958), and Waimakariri sand, on the youngest terrace which has been dated by Suggate (1958) as 5,000 years old. An older soil, Lismore sandy loam dune soil, was not sampled because of possible loess contamination.

There are also coastal dunes, and soils from two sets of these were also investigated. These were Waikuku sand of about the same age as Waimakariri sand, and Kairaki sand, a more recent sand. These sands, although coastal, are derived from debris carried to the coast by the rivers and hence should be very similar to the river sands.

Results of Analysis

The results of mechanical analysis of these soils are quoted in Table 5. These figures show a sharp variation in clay content, the lower horizon of all profiles containing about 1% of clay, and the upper horizons containing up to 10%. This probably represents contamination with loess, to a greater or lesser degree. The extractable iron content is low, indicating that little weathering of the primary minerals is going on.

The heavy mineral content of these sands is low, about 1%, and very different from the assemblage found in the North Island sands. These sands are derived mainly from greywacke alluvium and contain very few augites or hornblendes but mostly epidotes, with apatite and zircon.

TABLE 5—Sand Soils from near Christchurch

Sample No.	Depth, in.	Sand				Silt 20–2μ %	Clay <2μ %	Extr. Fe %	Heavy Minerals in Sand Fraction	
		>350μ %	350–150μ %	150–76μ %	76–20μ %				Non-Mag. %	Mag. %
Kairaki sand, Waikuku Beach. S76, 068850										
7149A	0–2	–	40·8	38·4	1·9	10·5	8·1	0·28	2·4	–
B	4–9	–	44·9	52·1	1·1	0·5	1·2	0·19		
Waikuku sand, near Kaiapoi. S76, 029772										
7148A	0–3	–	46·9	50·2	0·9	1·2	0·6	0·19	1·2	–
B	5–9	–	33·5	62·3	0·6	0·4	1·0	0·19		
Waimakariri sand, 2½ miles N.E. of West Melton										
7150A	0–4	–	21·7	32·1	30·2	9·7	5·8	0·46	1·2	–
B	16–22	0·2	33·6	54·1	9·4	1·1	1·4	0·25		
Paparua loamy sand, dune soil, ½ mile north of West Melton										
7151A	0–3	0·5	20·7	30·5	30·6	10·8	6·9	0·39	0·7	
B	9–12	1·9	26·1	26·1	25·1	11·3	7·5	0·48		
C	16–22	0·4	48·0	43·8	4·4	0·9	1·5	0·15	1·2	

The composition of the clay fraction is identical in all of the samples and consists of hydrated and partially hydrated micas and chlorite. Differential thermal analyses show a characteristic pattern of fusion at about 900° which has been identified as clay-vermiculite by Fieldes (1955), a common component of many South Island soils. This thermal effect was better developed in these samples than in any other South Island soil, and was not observed in any of the other sand soils studied. This marked difference in clay mineralogy is related to the origin of the fine clay size material which, in this case, is derived largely from finely crushed rock flour rather than from previously weathered soil material. This implies that the clays are of loessial origin, in common with most of the soils of Canterbury. It is obvious that from observations made during north-westerly conditions that a considerable quantity of wind-blown dust is being deposited on all the soils of the plains, and the clays of these soils would be derived from this source, rather than from weathering in the soil.

Although these soils are on terraces of considerable age, compared with the oldest of the Manawatu soils, they have not accumulated much clay size material, even though there is much fine material being blown over the soil, and they may mean that the soils are considerably younger than the surfaces on which they have accumulated.

CONCLUSIONS

The principal conclusion to be drawn from these results is that the greater part of the clay minerals of a sand soil are not formed in the soil but blown in. The existence of sand dunes means that there is a source of sand, usually a beach, kept supplied with sand by coastal drift or other means, while prevailing winds blow the sand inland. Any fine material carried in suspension by the sea would also be blown inland once it had dried out, as this would be carried further than the sand it would be deposited in a loess-like fashion over older sand dunes and other soils. This clay would be derived from material eroded from the surrounding country and carried down to the sea in rivers and streams, and therefore would contain the same clay minerals as the soils of the region, modified by alteration during transport in the streams and in the marine environment. As the greater part of New Zealand soils contain micaceous clay minerals, these are the minerals found in the clay fractions of sand soils. The sand grains themselves would be ground up, producing clay size quartz and feldspar particles, which are common, if not universal, minerals of the clay fractions of sand soils. Where there are other clay minerals locally present, e.g., halloysite in Taranaki and Waikato soils, kaolin and gibbsite in North Auckland and montmorillonite in the Gisborne region, these minerals are represented in the sand soils as well.

This is borne out by the variations in clay content shown in the soils of the Manawatu sand country, but also recognisable in other areas. The older the soil the longer it has to collect a topdressing of fine material.

Similarly, the more moist a soil is, the more of this clay it will be able to retain. This effect may also be related to the better growth of vegetation in moist sites.

Weathering of the clay in the soil is negligible in South Island sand soils, and there are no obvious differences in the mineralogy along the age sequences. The sequence from the Manawatu sand country shows some differences caused by weathering of the clay minerals. In the younger soils these appear to be amorphous material combining with the organic matter derived from solution of the fine quartz and feldspar particles. The clay minerals themselves show increasing hydration with age. A little tubular halloysite is found in the oldest soil of the sequence, but this could be caused by the presence of a little ash in this soil.

Even in the soils of North Auckland micaceous minerals are present, but other minerals, halloysite, kaolin and gibbsite, are present, and sometimes even dominant. However, the picture is complicated by the fact that the older sands where examined are not wind-blown but water deposited. At first sight it would appear that the presence of kaolin and gibbsite is related to the age and weathering of the soils, but as the distribution of gibbsite shows, these minerals are already present in the parent sandstones, and their ultimate origin cannot be determined. They are also present in the clay mineral assembly in younger soils, but in these cases they are derived from erosion of the older sands which outcrop on the coast.

The mineral-organic matter complex was not observed in the North Auckland soils, probably because such soils as Pinaki and Marsden are too young to develop any large amounts of organic matter, and older true wind-blown soils are rare.

THE POSITION OF THE SAND SOILS IN THE GENETIC CLASSIFICATION

Soils derived from coastal sand drifts are termed yellow-brown sands in the New Zealand Genetic Classification of Soils (Taylor, 1948; Taylor and Cox, 1956). They are in the intra-zonal group because of their youth; the soil has not had time to develop the characteristics of the zonal soils that would form under similar conditions of climate and vegetation. This means that in time, zonal soils will form on such sands, and this is observed in the most weathered of the soils discussed in this paper.

The clay mineralogy of yellow-brown sands, therefore, should be characteristic of an earlier stage of weathering than found in zonal soils of the same district. As has been shown in this paper the clays of the younger sand soils are not derived to any large extent from weathering *in situ* but are transported, with their ultimate origin mainly in zonal soils of surrounding areas. Hence the clay minerals are in general in harmony with their environment, in type if not in quantity. In the sands from Canterbury, for example, the clay minerals are similar to those found in the yellow-grey earths of the Canterbury plains while in the sand soils of the Manawatu district the clay minerals are characteristic of weakly weathered yellow-brown earths.

In North Auckland, however, where weathering processes are stronger, soils from sand show more variation. The soils classified as yellow-brown sands still show to some extent the youthful nature of the soil. However, a gradation is seen from soils where clay is low and most of it derived from airborne dust to soils where some of the clay is derived from weathering and affected markedly by weathering processes. For this reason the Tangitiki and Te Kopuru soils are not classed as yellow-brown sands but as a sandy yellow-brown earth and a sandy podzol respectively. Because the clay minerals of these two soils are largely inherited from the parent material, these soils are not truly zonal from a clay mineral aspect, but morphologically they are close to zonal soils.

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FORAMINIFERA FROM AN ALTERNATING SEQUENCE, EKETAHUNA, NEW ZEALAND

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Abstract

Samples systematically collected from an outcrop of Tongaporutuan alternating strata, Eketahuna, have been studied in terms of stability of the microfauna and size-frequency distribution of one species. Specific composition of the fauna shows little change from bed to bed but relative abundance of some groups varies widely. Size-frequency distributions of *Uvigerina miozea* Finlay may indicate a little modified life assemblage.

Introduction

Previous studies of New Zealand sequences of alternating strata (Kingma, 1958; Glennie, 1959; Webby, 1959) have dealt with lithologic characters; this paper seeks to complement these previous accounts with microfaunal information. Because the study has been planned as an investigation of several microfaunal techniques to assess their potential in the analysis of alternating strata, the results presented are based upon a limited sampling scheme, and no particular claim is made for their generality.

Earlier studies of microfaunas from alternating sequences (Natland and Kuenen, 1951) and from deep-sea sands (Phleger, 1951) have applied the conventional paleoecological technique of depth-range analysis. Phleger found benthonic Foraminifera characteristic of much shallower water in deep-sea sands in the San Diego trough and in the Sigsbee Deep. Natland and Kuenen (1951), studying faunas from the Pliocene of the Ventura Basin, found repeated evidence, on analogy with Recent distributions, of deep water Foraminifera contained in coarse sandstone-shale sequences previously considered to represent shallow water environments. This approach depends upon a detailed knowledge of the distribution of Recent Foraminifera, virtually an untouched field in New Zealand; moreover its applicability falls off rapidly through the Tertiary due to the changing specific composition of the microfaunas. An object of this paper is to investigate forms of microfaunal analysis which do not rely upon intimate knowledge of Recent foraminiferal distributions but which may still provide useful environmental information.

Faunal Stability

The problem investigated in this section relates to the stability of the microfaunal assemblage throughout the deposition of successive sandstone and siltstone beds. This question appears to be of significance in relation to both of the theories of origin of alternating strata at present being tested in New Zealand: the redeposition theory (Kuenen and Migliorini, 1950) which has been applied by Cotton (1951), Glennie (1959), and Wellman (1959); and the "Basin and Bar" theory of Kingma (1958).

N.Z. J. Geol. Geophys. 4 : 73–88

Cotton (1951) considered, on the hypothesis of redeposition of sediments, that sand beds in an alternating sequence may contain transported shallow water Foraminifera, and it may be further supposed on this line of argument that the faunal component of the siltstones would in some way differ from that of the sandstones, due to the progressive change in hydrodynamical conditions during deposition. For example, Greenman and LeBlanc (1956) consider that turbidity current transport of sediments in Sigsbee Deep, N.W. Gulf of Mexico, would result in a definite layering or separation of indigenous and derived faunas. Kingma (1958, p. 28) to the contrary supposed that Foraminifera would recolonise the site of deposition during the silt phases, the sand phases causing depletion of faunas but not total suppression. Here again it is pertinent to assess the stability of the microfauna from bed to bed.

Sampling Details and Lithology

West of Pongaroa, northern Wairarapa, lies a widespread sequence of alternating strata, mainly Tongaporutuan in age. Roadside and stream outcrops are plentiful, and the particular beds sampled were in no way especially selected. Choice was haphazard, if not truly random. Fig. 1 gives the spatial details of the sampling grid (N154/521) put over an outcrop on Upper Mangatiti Road, approximately 200 yd west of the concrete bridge over Mangatiti Stream (N.Z.M.S. 1 N154/558125). Samples were taken at the predetermined loci with a circular metal punch having a diameter of 0·75 in. Fifteen grams of each air-dried sample were boiled and washed over a standard 230-mesh sieve. Several of the samples were placed in silk and gently rubbed by hand to ensure adequate disaggregation.

Lithological description of sediments from the five sampling horizons is based upon cumulative grain-size distributions prepared by Dr J. T. Kingma. Table 1 lists relevant parameters taken from these curves, phi-median diameter (Mdϕ) phi-mean (Mϕ) phi-deviation ($\sigma\phi$) and phi-skewness ($\alpha\phi$). The coarsest sample judged by the median diameter is that from the B-level near the base of the sandstone unit; this horizon also shows the greatest degree of sorting, $\sigma\phi = 0{\cdot}8$. The sample from C-level, near the top of the sandstone exhibits a median diameter of 4·3 ϕ and shows poorer sorting, $\sigma\phi = 2{\cdot}05$. Parameters for samples from D- and E- levels show that "fining" of the sediment continues towards the top of the siltstone. Better sorting is found in these samples than in those studied by the author (Scott, 1958), which were considered to represent an "outer shelf" environment. However, sorting is inferior to that obtaining in the Recent sediments of Todos Santos Bay (Walton, 1955). Skewness is least in the samples from the top of the siltstone units and reaches greatest magnitude in the sandstone bed.

Census Results and Tests of Hypothesis

The entire microfauna in each sample was counted; however, as counting was non-replicative, operator error in this phase of the study remains unassessed. Some species are much more readily identified than others when present as juveniles or as broken specimens, and counting error is clearly related to this.

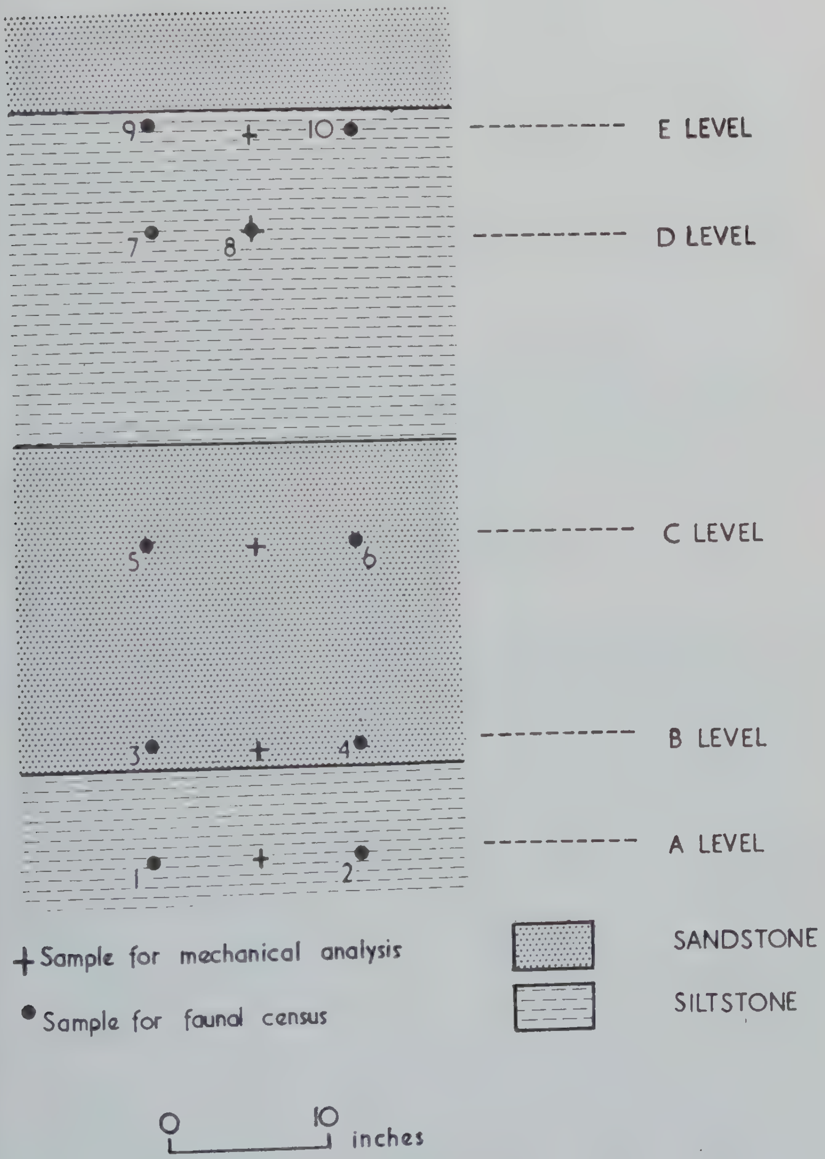


FIG. 1—N154/521, Upper Mangatiti Rd, position of samples for faunal census and mechanical analysis.

TABLE 1—Grain-size parameters, phi-median ($Md\phi 3$), phi-mean ($M\phi$), phi-skewness ($\alpha\phi$), and phi-deviation ($\sigma\phi$) for samples from A to E levels.

——	$Md\phi$	$Md\phi$	$\alpha\phi$	$\sigma\phi$
E-level	6.1	5.9	1.4	−0.14
D-level	5.1	5.7	1.9	0.32
C-level	4.3	5.0	2.0	0.34
B-level	3.6	3.8	0.8	0.25
A-level	5.8	5.8	1.6	0.00

The stability of the fauna through successive beds may be investigated from several directions. Firstly stability may be assessed through comparison of species lists. To facilitate expression of degree of similarity a simple index used by Kontkanen (1957) has been applied. This is the quotient of similarity (QS) expressed as

$$\mathrm{QS} = \frac{2c}{a+b} \cdot 100$$

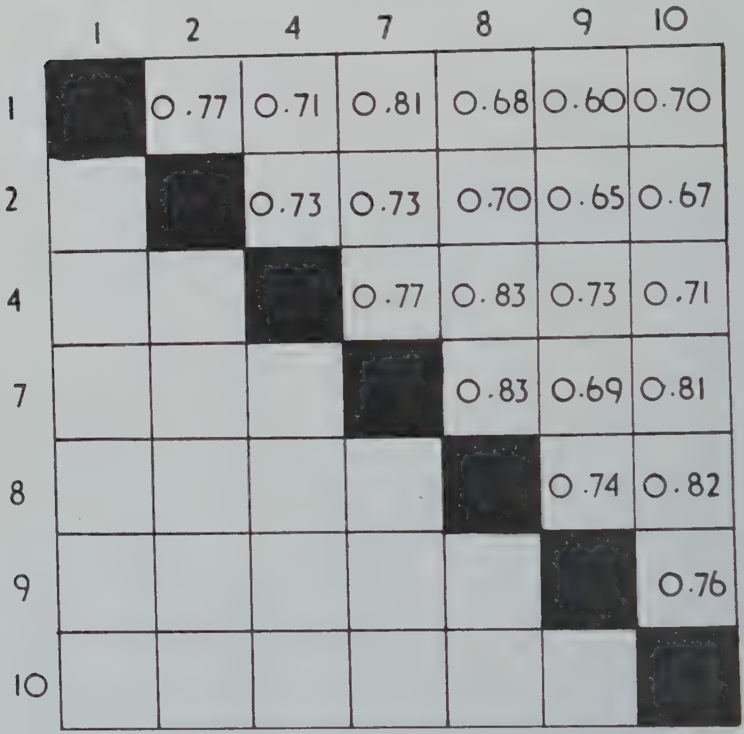
where a represents the number of species found in Sample A and b the number in sample B, and c is the number of species common to the two faunas A and B. Table 2 gives the distribution of species or generic groups for samples 1 and 2 from the lower siltstone bed, sample 4 from the sandstone, and samples 7–10 from the upper siltstone bed. Samples 3, 5, and 6 have been omitted from the table as they contained only a few damaged specimens. Fig. 2 lists QS values for the samples listed in Table 2. Perhaps the major feature shown by this figure is that the QS values involving sample 4 from the sandstone appear not to lie outside the values computed for samples within either siltstone bed or for values involving comparison between the two siltstone beds. Although only one of four samples from the sandstone produced more than a few individuals, the species present are those which occur in the adjacent siltstones. The matrix of QS values is therefore interpreted as indicating faunal homogeneity on the basis of specific composition within the grid. Investigation of Table 1 shows that several members of the fauna present in the upper siltstone bed are nevertheless absent from the lower; most notable of these are *Bigenerina pliocenica* Finlay and *Cibicides* sp. (deeply punctate).

Stability of the fauna may also be studied in terms of group abundances, to discover whether or not the abundance of one group maintains a constant ratio to that of another throughout a set of samples. Samples and species may be arranged in the form of a contingency table, theoretical frequencies calculated from the marginal totals of the table on the assumption that the ratio is constant for all samples in the table, and the X^2 test applied to assess the significance of the difference between observed and computed frequencies. Table 3 tests the hypothesis that *Uvigerina miozea* and *Bolivinita*

TABLE 2—Distribution of Taxonomic Groups in Samples 1, 2, 4, 7–10, N154/521

	1	2	4	7	8	9	10
Textularia sp.	x	x					
Bolivinopsis sp.						x	
Haeuslerella morgani Finlay	x	x	x	x	x		x
Bigenerina pliocenica Finlay					x	x	x
Karreriella cylindrica Finlay		x		x	x	x	x
Miliolid	x		x				
Sigmoilopsis sp.					x		
Robulus aff. *calcar* (Linné)	x	x				x	
Stilostomella globulifera (Kreuz)	x	x	x	x	x	x	x
Lagenodosaria sp.						x	x
Nonion and *Astrononion* spp.	x	x	x	x	x	x	x
Notorotalia taranakia Vella	x	x	x	x	x	x	x
Bolivinita pliozea Finlay	x	x	x	x	x	x	x
Plectofrondicularia whaingaroica (Stache)						x	
P. pellucida Finlay						x	
Bolivina aff. *parri* Cushman	x	x	x	x	x	x	x
Bolivina affiliata Finlay	x		x	x	x	x	x
Bolivina sp.	x	x	x	x	x	x	x
Rectobolivina parvula Finlay				x			
Virgulina sp.		x	x		x	x	
Bulimina senta Finlay						x	
Bulimina aff. striata (d'Orb)	x		x	x	x	x	x
Bulimina sp.					x		
Uvigerina miozea Finlay	x	x	x	x	x	x	x
Pleurostomella sp.			x		x		
Epistomina elegans (d'Orb)			x			x	
Epistominella sp.			x	x	x	x	
Gyroidina prominula (Stache)		x	x			x	
Sphaeroidina bulloides (d'Orb)		x	x	x	x	x	x
Pullenia bulloides (d'Orb)	x			x			
Cassidulina spp.	x	x	x	x	x	x	x
Cibicides deliquatus Finlay	x	x		x			
Cibicides ihungia Finlay	x	x	x	x	x	x	
Cibicides sp. (sinuous ventral sutures)	x	x	x	x	x	x	x
Cibicides sp. (deeply punctate)				x	x	x	x
Anomalinoides parvumbilia (Finlay)	x		x	x	x	x	x
Laticarinina halophora (Stache)						x	
Globigerina spp.	x	x	x	x	x	x	x
Globorotalia miozea Finlay						x	x

pliocea occur in the ratio 128 : 77 in both of the samples from the lower siltstone. As there is only one degree of freedom in this table, Yates' correction for continuity is applied and X^2 computed as 4·87; probability of a greater value is less than 0·05. This result would suggest that there may be a real difference between the hypothetical and observed values in the table; there is certainly cause to doubt the hypothesis of homogeneity of ratios. Table 4 applies a similar hypothesis to the data for *Uvigerina miozea* and *Bolivinita* *pliozea* from the upper siltstone samples. Here there is no reason to doubt the hypothesis ($P > 0\cdot5$) that a constant ratio is maintained between the two species within the 4 samples. Table 5 tests the hypothesis of homogeneity of ratios for four groups in the samples from the upper siltstone bed. Again there is no reason to reject the hypothesis of homogeneity ($P > 0\cdot1$); this is an interesting result because a pelagic group (*Globigerina* spp.) is incorporated in the table together with three benthonic species.



	1	2	4	7	8	9	10
1	■	0.77	0.71	0.81	0.68	0.60	0.70
2		■	0.73	0.73	0.70	0.65	0.67
4			■	0.77	0.83	0.73	0.71
7				■	0.83	0.69	0.81
8					■	0.74	0.82
9						■	0.76
10							■

FIG. 2—Matrix of Quotient of Similarity Values for samples 1, 2, 4, 7–10.

Stable interspecific abundances within the upper siltstone are not maintained by all species; Table 6 lists the actual and theoretical frequencies for *Uvigerina miozea* and *Bolivina* aff. *parri* from this bed. Differences are so large as to make application of the X^2 test unnecessary. *Cassidulina* spp. (Table 7) is another group whose distribution is at variance with *Uvigerina miozea*. It seems that the distribution of groups such as *Bolivina* aff. *parri* and *Cassidulina* spp. contributes toward the rejection of the hypothesis of homogeneity (tested in Table 8) for the relation between *Uvigerina miozea* and the remainder of the population in samples from the upper siltstone.

TABLE 3—Distribution of *Bolivinita pliozea* Finlay and *Uvigerina miozea* Finlay in samples 1 and 2 from the lower siltstone bed with test of homogeneity of relative abundance

——	Sample		Total
	1	2	
Uvigerina miozea	75	53	128
Bolivinita pliozea	32	45	77
TOTAL	107	98	205

$$\chi^2 = \frac{205\left[(75\times 45)-(53\times 32)-\frac{205}{2}\right]^2}{(128)\quad(77)\quad(107)\quad(98)} = 4{\cdot}87$$

$$\text{d.f.} = 1 \qquad P < 0{\cdot}05$$

Homogeneity tests have been applied only to those groups which, because of their distinctive morphology, are least likely to have caused operator errors in counting. When one point in the assemblage (*Uvigerina miozea*) is selected and tested for homogeneity of relative abundance with other groups in the manner carried out here, the assemblage appears broadly divisible into species maintaining fairly uniform relative abundances and those that are quite independent. This situation appears to be much more comparable to that discussed by Clark and Milne (1955) where the invertebrate macrofauna of the sea bottom was found to be composed of both aggregated and non-aggregated species, than that which would result from wholly mechanical sorting of the fauna. The question of aggregation or non-aggregation of the fauna cannot be adequately analysed here because the samples are drawn from a stratigraphic section, and hence are related to varying rates of sedimentation.

TABLE 4—Distribution of *Bolivinita pliozea* Finlay and *Uvigerina miozea* Finlay in samples 7–10 from the upper siltstone bed with independence frequencies and test of homogeneity of relative abundance

——	7	8	9	10	TOTAL
Uvigerina miozea ...... theoretical freq.	70 77.12	55 51.77	189 184.89	60 60.22	374
Bolivinita pliozea ...... theoretical freq.	76 68.88	43 46.23	161 165.11	54 53.78	334
TOTAL	146	98	350	114	708

$$\chi^2 = 2{\cdot}02 \qquad \text{d.f.} = 3 \qquad P > 0{\cdot}5$$

TABLE 5—Distribution of *Bolivinita pliozea* Finlay, *Uvigerina miozea* Finlay, *Notorotalia taranakia* Vella and *Globigerina* spp. in samples 7–10 from the upper siltstone bed with independence frequencies and test of homogeneity of relative abundance

——	7	8	9	10	TOTAL
Uvigerina miozea	70	55	189	60	374
theoretical freq.	75.13	57.16	180.06	61.65	
Bolivinita pliozea	76	43	161	54	334
theoretical freq.	67.09	51.05	160.80	55.06	
Notorotalia taranakia	17	11	24	8	60
theoretical freq.	12.05	9.17	28.89	9.89	
Globigerina spp.	21	31	67	29	148
theoretical freq.	29.73	22.62	71.25	24.40	
TOTAL	184	140	441	151	916

$X^2 = 13{\cdot}75$ d.f. $= 9$, $P > 0{\cdot}1$

TABLE 6—Distribution of *Uvigerina miozea* Finlay and *Bolivina* aff. *parri* Cushman in samples 7–10 from the upper siltstone bed with independence frequencies listed

——	7	8	9	10	TOTAL
Uvigerina miozea	70	55	189	60	374
theoretical freq.	110.73	65.38	161.38	36.52	
Bolivina aff. parri	118	56	85	2	261
theoretical freq.	77.27	45.62	112.62	25.48	
TOTAL	188	111	274	62	635

TABLE 7—Distribution of *Uvigerina miozea* Finlay and *Cassidulina* spp. in samples 7–10 from the upper siltstone bed with independence frequencies listed

——	7	8	9	10	TOTAL
Uvigerina miozea	70	55	189	60	374
theoretical freq.	62.06	45.14	211.99	54.81	
Cassidulina spp.	7	1	74	8	90
theoretical freq.	14.94	10.86	51.01	13.19	
TOTAL	77	56	263	68	464

TABLE 8—Distribution of *Uvigerina miozea* Finlay and the remainder of population in samples 7–10 from the upper siltstone bed with independence frequencies and test of homogeneity of relative abundance

——	7	8	9	10	TOTAL
Uvigerina miozea ……	70	55	189	60	374
theoretical freq. ……	112.86	62.06	158.38	40.69	
Remainder of population ……	701	369	893	218	2181
theoretical freq. ……	658.14	361.94	923.62	237.31	
TOTAL ……	771	424	1082	278	2555

$X^2 = 38{\cdot}18$ d.f. $= 3$, $P < 0{\cdot}01$

SIZE-FREQUENCY DISTRIBUTION OF *Uvigerina miozea*

Recent studies by Boucot (1953), Olson (1957) and Rigby (1958) have shown that information valuable for the discrimination of life from death assemblages (in the sense of Boucot, 1953) may be gained from the study of size-frequency distributions of extinct organisms. *Uvigerina miozea* Finlay has been selected for study here because of its abundance in samples from the grid, and because of the relatively large size of its early growth stages. This latter condition is important when only that fraction of the sediment which is retained on a 230-mesh sieve is available for study. Figs. 3 and 4 present as histograms, maximum length measurements, excluding the apertural spout, for samples of *Uvigerina miozea* from both siltstone beds. A bimodal distribution is apparent.

These histograms must be interpreted in the first instance in relation to the growth and mortality curves of living foraminiferal populations. One of the best documented descriptions of the bionomics of a foraminiferal species living under natural conditions is that provided by Myers (1942, 1943) for *Elphidium crispum* (Linné). From sampling conducted in Plymouth Sound, Myers found (1943, p. 443) that the rate of chamber increment ". . . depends upon the need for growth that results when food is consumed in excess of the basic requirements of the organism. When adequate food is available, growth is continuous". The asymptotic winter segment of the growth curves constructed by Myers (1943, Fig. 3 and 1942, Fig. 5) is therefore due to contraction of food resources. As the food supply expands in the following spring, growth is resumed and is continuous until reproduction occurs. Now it could be objected that a growth curve of the type shown in Fig 5 holds only for regions where seasonality is pronounced, and may not reasonably be taken as a model for a Tertiary population which grew under an unknown climatic regime. However, study of *Elphidium crispum* in the Java Sea (Myers, 1943, p. 447) shows that even under these low latitude conditions, a period of comparative dormancy, probably due to diminution of food supply, does occur, followed by a brief period of growth leading to reproduction. The

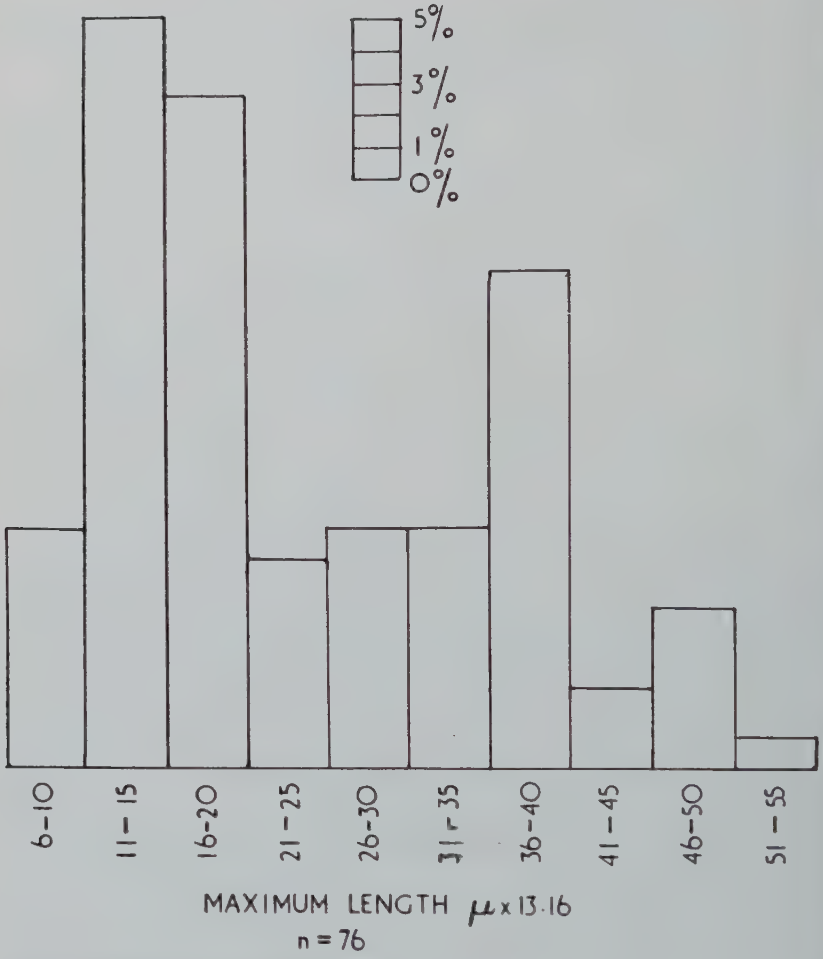


FIG. 3—Size-frequency distribution of *Uvigerina miozea* Finlay from samples 1 and 2, lower siltstone.

growth curve shown in Fig. 5 therefore appears to be quite valid for *Elphidium crispum* in all regions, and the nature of the food: growth relation in this species probably applies generally within the smaller foraminifera.

Only a rough assessment of the survivorship of *Elphidium crispum* is given by Myers (1942, p. 337–8). For tide-pool and sub-littoral conditions, Myers considers that mortality in early age groups is high because they are used as food by many other small invertebrates. Later, the size of the tests makes them unsuitable as food for these organisms. It appears, therefore, that the mortality rate is initially high during the juvenile stages, probably progressively lessening until the period of reproduction is reached when it must again increase. The sigmoid curve B2 shown in Fig. 2 of Pearl and Miner (1935) would approximate such a survivorship pattern.

Now if the age structure of the population is stable, with recruitment of each age class being approximately balanced by deaths in that class, then

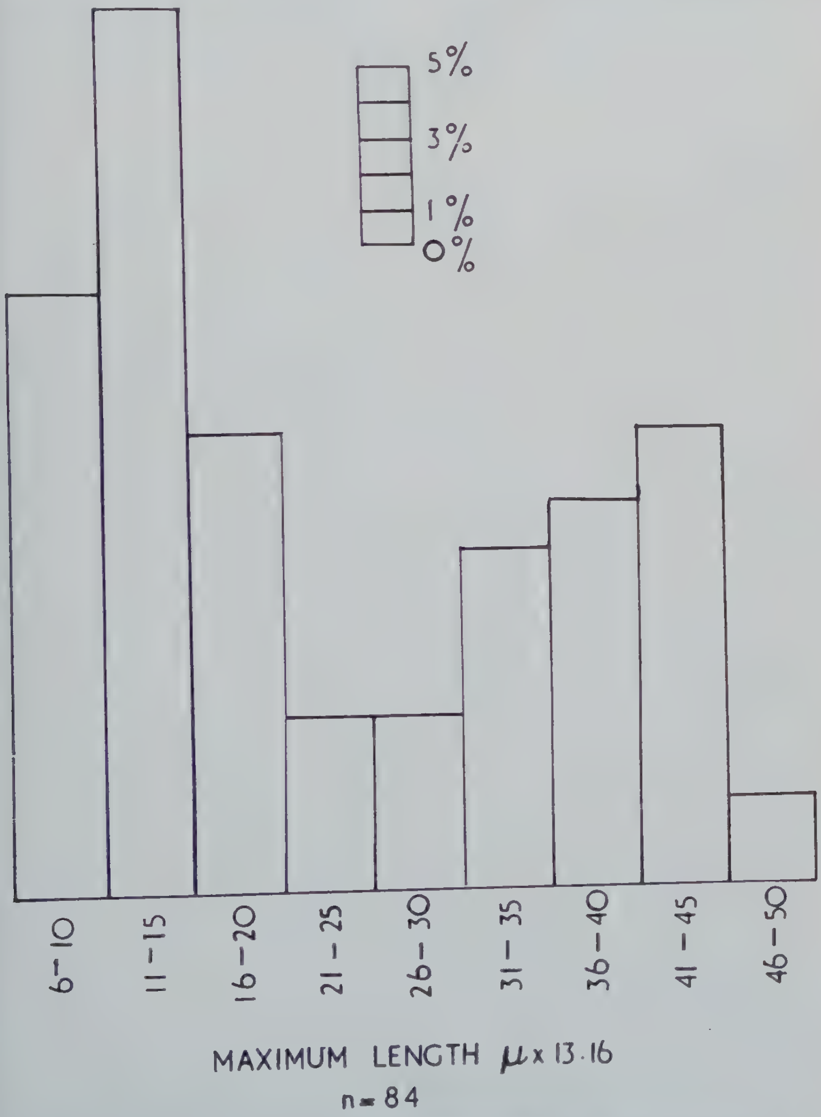


FIG. 4—Size-frequency distribution of *Uvigerina miozea* Finlay from sample 9, upper siltstone.

the size-frequency distribution of individuals contributed to the sediments may be arrived at by plotting the survivorship curve against the growth curve. Fig. 5 shows such a plot, using the type of growth curve shown by Myers for *Elphidium crispum* and a survivorship curve of Pearl and

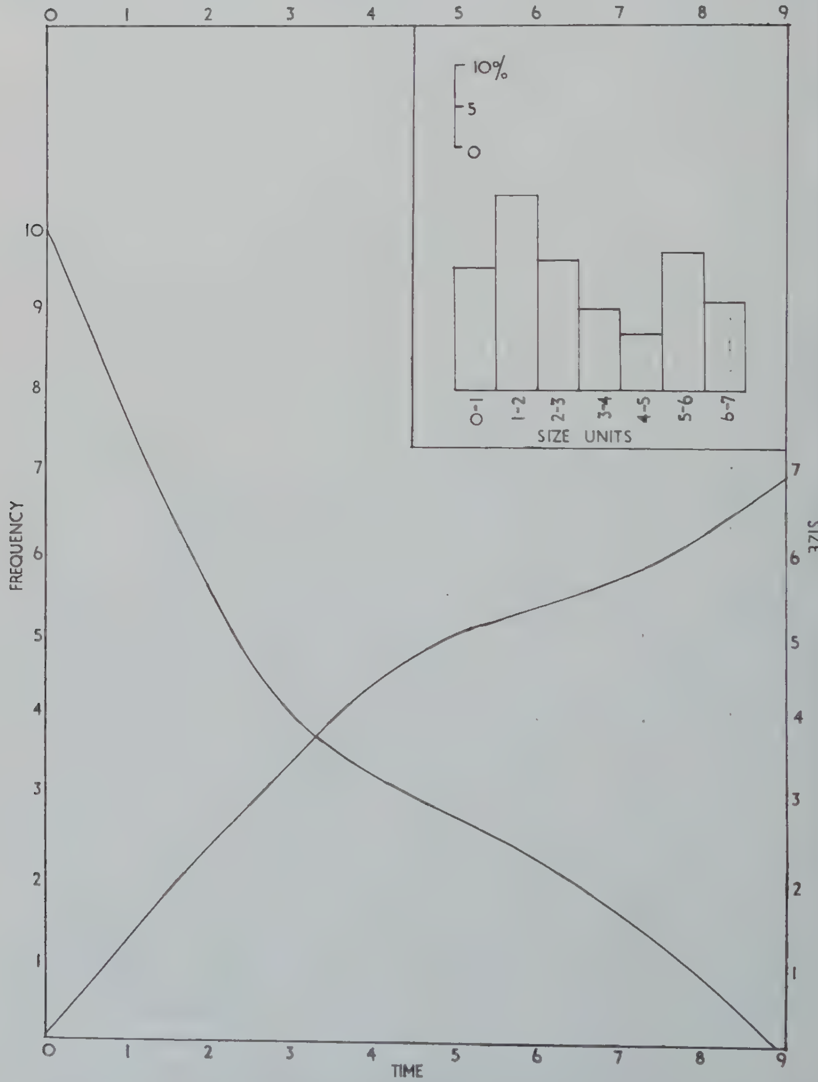


FIG. 5—Hypothetical survivorship and growth curves for a foraminiferal population based on graphs and qualitative description given in Myers (1942). Attention should be given to the form of these curves rather than their relative positions. Inset shows size-frequency distribution of dead tests derived from a population living under these conditions.

Miner's B-type. The distribution of size-frequencies is bimodal. From present knowledge of the biology of living populations, it therefore appears that bimodality in size-frequency distribution of empty tests of Foraminifera may reasonably be expected. Whether such distributions are to be found in ancient sedimentary environments depends entirely upon the processes to which the tests are subjected after death of the organism.

One means of assessing the effects of some of these processes is to consider the size-frequency distribution of *Uvigerina miozea* from other sedimentary environments. Fig. 6 shows the size distribution of this species from an exposure of massive, mid to upper Tongaporutuan siltstones at Waihoki Road (N154/571) some miles south of N154/521. Here the distribution of frequencies throughout the size classes is much more evenly spread and the bimodality seen in Figs. 3 and 4 is not apparent. Another type of distribution is seen in Fig. 7, based on a sample (N154/564A) from the base of a microbanded sandstone bed in Pareora Series alternating sediments from the lower reaches of Mangatiti Stream. A feature of

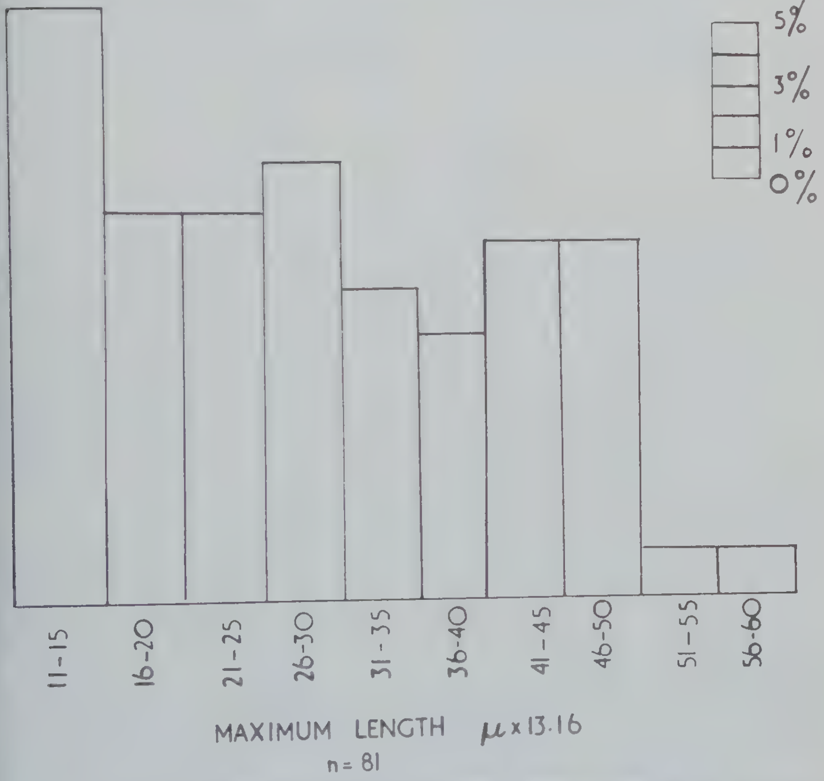


FIG. 6—Size-frequency distribution of *Uvigerina miozea* Finlay from N154/571, massive siltstone, Waihoki Rd.

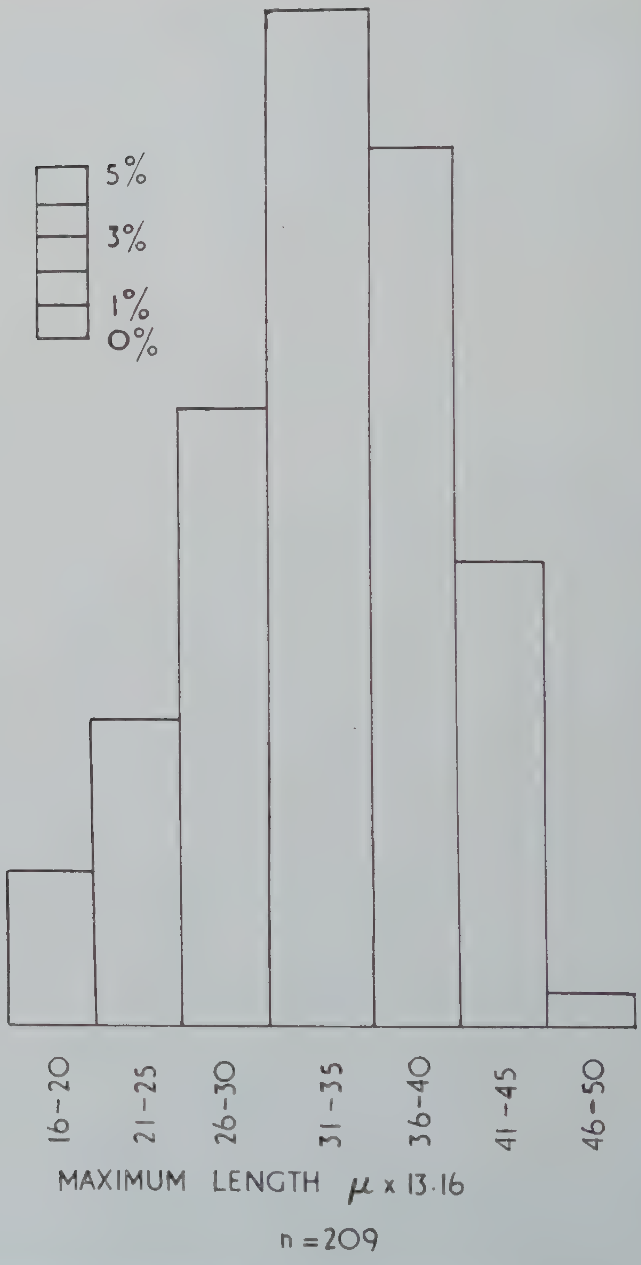


Fig. 7—Size-frequency distribution of *Uvigerina miozea* Finlay from N154/564A, base of microbanded sandstone, lower reaches of Mangatiti Stream.

this distribution is the absence of juveniles, and in this respect the curve seems analogous to the size-frequency curves for many fossil forms shown by Olson (1957, Figs. 13, 14, 15). Such curves are often fairly symmetrically unimodal, and must reflect effects of sorting. It is probable, therefore, that the size-frequency distributions shown by *Uvigerina miozea* in the siltstone beds of N154/521 may indicate a little modified life assemblage. Insufficient specimens of *Uvigerina miozea* were obtained from the sandstone bed of N154/521 to permit useful study of their size-frequency distribution; however, both juvenile and fully developed specimens are present in sample 4. This sandstone unit is not microbanded, although as pointed out previously, it is graded. The microbanded sandstone of N154/564A with its size-sorted population of *Uvigerina miozea* no doubt represents an entirely different set of sedimentary conditions from those obtaining during the deposition of the sandstone of N154/521.

CONCLUSION

Within the sampling area of N154/521 specific composition of the fauna from bed to bed is essentially homogeneous. Deposition of sandstones results in neither an influx of new species nor suppression of the siltstone fauna. Total population numbers per unit sample in the sandstone are lower than in adjoining siltstones, a condition reasonably attributable to fluctuation in rates of deposition (Walton, 1955). Variation in relative specific abundances in the siltstone beds appears more likely to be a result of original distributions than of subsequent physical processes. Size-frequency histograms of specimens of *Uvigerina miozea* in the siltstone beds show a pattern similar to an inferred original distribution; sorting for size is notably absent compared to that seen in other environments of sedimentation. All lines of evidence thus point toward a condition of sedimentation involving a stable microfaunal assemblage not greatly subjected to processes of mechanical sorting after death.

The methods applied in this study clearly do not lead to the spectacular results sometimes obtained by the depth-range approach; nevertheless, analysis of faunal stability and size-frequency distributions seems capable of providing useful depositional information. Of the two methods, that of size-frequency analysis is the more easily applied in a widespread sampling scheme, and could well provide a simple index of the extent to which a life assemblage has been modified by physical processes.

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DRILLHOLE EVIDENCE OF THE PLIOCENE-PLEISTOCENE BOUNDARY AT TIMARU, SOUTH CANTERBURY

By H. S. GAIR, New Zealand Geological Survey, Department of Scientific and Industrial Research, Christchurch.

(Received for publication, 24 August 1960)

Summary

Mollusca, Foraminifera, pollen grains and spores from a drill-hole show that at Timaru the Pliocene-Pleistocene boundary is at a depth of 300–310 ft below sea level, and that the boundary between marine and non-marine sediments is at least 100 ft above.

INTRODUCTION

The sequence of Pliocene and Pleistocene rocks in the Timaru district is given in the table below. (See also, Gair, 1959, Fig. 2 (a), p. 268.)

Formation	Lithology	Thickness in ft	Age
	Yellow silt (Loess)	5–60	Upper Pleistocene
	Coarse-grained basalt. Vesicular at the base and top.	up to 75	Lower Pleistocene
	Banded, graded-bedded, semi-consolidated, rust-red to yellow-brown coloured tuff.	1–2	
Cannington Gravels (Gair, 1959, p. 275)	Weathered greywacke gravels predominant in the top half, and silts, clays, and sands predominant in the bottom half.	up to 600	Lower Pleistocene to Upper Pleistocene

A hole was drilled (by cable tool) by A. M. Bisley and Co. Ltd., Christchurch, for the New Zealand Government Railways Department, Timaru, during the months March to May 1959, to a depth of 500 ft below the ground surface. The site (S111/788503 – 1942 Edn.) is 300 yd from the sea and is 10 ft above sea-level at the foot of a 30 ft cliff of loess, approximately 80 yd to the north of the locomotive sheds. The drill-hole passed through 28 ft of loess, 19 ft of basalt, 1–2 ft of tuff, and 440 ft of predominantly silts and silty clays of the Cannington Gravels, encountering gravel at the 53–71 ft, 413–416 ft, and 488–489 ft levels respectively.

According to the drillers' log (see Table 1), shells were first noticed in the cuttings from a depth of 326 ft in a "blue sandy clay", but those described in this paper came from a depth of 413–416 ft and were in a bed of unconsolidated, blue-grey greywacke gravel with a sandy matrix (see Table 1). This gravel is a typical unweathered beach gravel: all the pebbles are well-rounded and most are flattened; they are up to 5 in. across but are mainly ½–1½ in. across.

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TABLE 1—Log of a 6-in. Well Drilled for the Railways Department at Timaru

Depth Below Ground Surface (ft)	Driller's Log	Comments on the Log (H. S. Gair)
0 – 28	Yellow clay (loess)	There is a 30 ft cliff-face of loess above the borehole site giving a total thickness of 58 ft of loess
28 – 32	Yellow clay with some gravel	This gravel was not seen by the writer but is probably basalt fragments and not greywacke.
32 – 36½	Basalt rock	
36½ – 37½	Clay with some rock fragments	The upper surface of the basalt has joints and fissures filled with a brown clay which is either a residual clay derived from weathering of basalt or loess, or a mixture of both. These joints and fissures extend to a depth of several feet and the drillhole apparently passed through one of them.
37½ – 44	Basalt rock	
44 – 46	Rotten rock	The writer did not see this deposit but it is probably an altered zone similar to those exposed in quarries about Timaru.
46 – 51	Basalt rock	
51 – 53	Yellow cemented sands with some fragments	This is probably the rubbly base of the basalt and not a sedimentary bed although it may include the upper coarser part of the tuff.
53 – 58	Red sandstone with red gravels	The red sandstone is probably tuff and the red gravels are the top of the Cannington Gravels (Gair, 1959)
58 – 60	Red gravels, small, with clay	
60 – 62	Yellow clay and gravel	
62 – 67	Yellow clay and sand	
67 – 69	Soft red-brown cemented sands	
69 – 71	Red-brown gravel and sand	No further gravel until 413 ft.
71 – 81	Yellow clay	
81 – 82½	Cemented brown sands	
82½ – 98	Yellow clay	
98 – 99	Cemented brown sands	
99 – 129	Yellow clay	
129 – 134	Coarse yellow-brown sand	
134 – 136	Cemented yellow-brown sand	
136 – 178	Yellow clay	
178 – 180	Yellow clay and sand	
180 – 200	Yellow clay	

TABLE 1—*continued*

Depth Below Ground Surface (ft)	Driller's Log	Comments on the Log (H. S. Gair)
200 – 209	Blue clay	This colour change from yellow above to blue below possibly marks the transition from non-marine above to marine sediments below, or a former water table.
209 – 211½	Fine brown sand	
211½ – 227	Sticky blue clay	
227 – 235	Sandy blue clay	
235 – 237	Greenish blue silty clay	
237 – 239	Greenish blue sandy clay	
239 – 247	Blue silty clay	
247 – 272	Grey-blue sandy clay	
272 – 273	Dark brown sticky clay	
273 – 309	Blue sandy clay	
309 – 310	Dark brown sticky clay	
310 – 318	Blue sandy clay	
318 – 319	Dark brown clay	
319 – 326	Blue sandy clay	Carbonaceous material here according to driller
326 – 363	Blue sandy clay, with some shells and traces of peat	According to the driller this depth range was where he first noticed shell fragments
363 – 413	Blue sands with many silt lenses and some shells	
413 – 416	Well sorted and worn greywacke gravels and blue sand	The source of the fossil collection
416 – 434	Fine blue sands with some shells	
434 – 446	Blue and grey silty sands with some hard marl bands	
446 – 450	Blue silty sand	
450 – 457	Blue sandy clay	
457 – 458	Blue-green rock and clay	
*465 – 488	Blue clay	
488 – 489	Blue gravel	
489 – 500	Blue sand	

End of Hole

*458 – 465 Blue sandy clay

8-in. casing to 32 ft 6 in.

8-in. hole cut to 58 ft.

6-in. casing to 500 ft.

All casing subsequently removed.

Static Water level at a depth of 500 ft was 9 in. above ground level (= rail level) which is 10 ft above mean sea level.

The letters GS, F, and L, used in this paper, refer to macrofossil, foraminiferal and microfloral collections held by the New Zealand Geological Survey, Lower Hutt.

Macrofossils

Mrs G. H. Scott (née Miss A. U. E. Boreham), N.Z. Geological Survey, identified the following Mollusca from the bed of gravel at 413–416 ft.

Sheet Fossil Number S111/529 GS 7234

Anomia sp.
Baryspira mucronata (Sowerby)
Buccinulum (*Euthrenar*) sp.
Dosinia (*Austrodosinia*) cf. *anus* (Philippi) (Not the Upper Nukumaruan *horrida*)
Eumarcia plana (Marwick) (not post-Nukumaruan)
Glycymeris (*Manaia*) sp. (many fragments)
Maoricrypta radiata (Hutton)
Perna canaliculus (Gmelin) (Opoitian-Recent)
Pervicacia sp.
? *Tanea* sp. (fragment)
Tawera spissa (Deshayes) (one fragment only) (Not the Upper Waitototaran – Upper Nukumaruan *subsulcata*)
? *Zeacumantus* sp.

Fossils were scarce, and the writer had to search through the gravel sludge for some hours in order to obtain the above collection.

Age

Mrs Scott supplied the following note:

"Waitotaran. *Glycymeris (Manaia)* not usually later than Lower Waitotaran but may persist until Middle-Upper Waitotaran as at Motunau."

Microfloras

The driller had collected samples at 10-ft intervals and 23 of these samples were forwarded to Dr W. F. Harris for examination. His results are tabulated below.

Sheet Fossil Number	L Number	Depth (ft)	Age and Remarks
S111/551	1247	60–62	No flora
550	1251	67–71	
549	1250	129–134	
548	1249	134–136	
547	1248	200–220	
546	1252	220–230	Cool to cold flora – extinct types rare. Hystrichospherids (i.e., almost certainly marine)
545	1253	230–240	No flora
544	1254	240–250	
543	1255	250–260	Cold flora. Grass and Compositae pollen exceed tree pollen (beeches and conifers) Conifer mainly *Dacrydium bidwillii* type with *Phyllocladus* (*? alpinus*)

542	1257	260–270	Cool to cold flora. Extinct types rare
541	1256	270–280	No flora
540	1213	280–290	No flora
539	1206	290–300	Poor flora. One extinct type (*Polypodiidites inangahuensis*)
538	1205	300–310	Very few extinct pollens. (*Triorites harrisii* only). Waitotaran to lower Nukumaruan. Very probably L. Nukumaruan.
537	1204	310–320	Poor flora. Extinct beeches.
536	1203	320–330	Cool flora. Extinct beeches. Waitotaran to Lower Nukumaruan. Very probably Waitotaran. Hystrichospherids.
535	1202	330–340	Mild to cool flora. Hystrichospherids. Beech (probably mainly red beech) dominant.
534	1201	340–350	Mild to cool flora. Red beech and conifers including ?kauri. Extinct beeches and *Triorites harrisii* (extinct). Hystrichospherids.
533	1212	350–360	No flora
532	1211	360–370	Probably Waitotaran, but near the border line. Hystrichospherids.
531	1210	370–413	„

Dr Harris made the following comments on the floras:

"From the deepest sample examined for pollen, taken at a depth of from 413–370 ft below the surface (S111/531) a pollen flora was obtained quite comparable with a flora (to be described elsewhere) from near Glenhope (about midway between Westport and Blenheim), to which on pollen and on stratigraphic evidence a Waitotaran age was assigned. Such differences as there are in the two floras would readily be attributed to a somewhat drier climate for the Timaru station. Beech pollen is dominant, the important species evidently in both cases was *Nothofagus fusca* (red beech). Similar floras were found also in two samples ranging from 340 to 320 ft below the ground surface. Between 310 and 300 ft the only significant change seems to be in the disappearance of the pollen types *Nothofagus cranwellae* and *N. matauraensis* which represent a group of beeches now extinct in New Zealand. Pollen of *Triorites harrisii* is still present, but in samples between 270 and 250 ft it has dropped to very low frequency. The proportion of tree pollen has diminished markedly while that of grass and herbs has increased so that at the 260–250-ft level pollen of composites just exceeds the total tree pollen. The spores of ferns are also less frequent, especially of tree ferns. In the sample from 230–220 ft the trend towards dominance of non-tree pollen is reversed, but it is still a cool flora. A few grains of the extinct species *Triorites harrisii* and the conifer *Microcachryidites parvus* are still found. *Trilites bowenii*, not hitherto found in beds older than ?Hawera age appears. Hystrichospherids are present and the occurrence of what was thought to be *Botryococcus* was noted. These indicate a marine environment. In the tabulated results above, the remarks were based on stratigraphic ranges, and it is on these grounds that a Waitotaran age was suggested for the bottom of the profile. The change noted above between 230 and 220 ft may have been a minor fluctuation, and the maximum cold could have occurred further up the sequence when the environment was no longer marine (low sea-level). Unfortunately, failure to get pollen prevents examination of this hypothesis. The placing of the boundary between the Waitotaran and Nukumaruan stages, and thus between the Pliocene and the Pleistocene is of necessity arbitrary. It is suggested that the stratigraphic relationships can best be indicated in this instance by taking the change as at 300 ft below the surface. There is much reason to suppose that the climate has been gradually cooling, with possible fluctuations, since the mid-Miocene, and placing the boundary at this point agrees with the conception of the final reduction and extinction of thermophilous types of the Tertiary, the change to cool temperate vegetation with highly segregated small-leaved evergreen forest types, and the cooler fluctuating Quaternary climates. It likewise agrees with the supposition that as the time-stratigraphy boundary was crossed, these changes were slightly more advanced in the latitude of this bore-hole than in the latitude of the Frankton Drill hole studied by Couper and Harris (1960)."

Microfaunas

Messrs N. de B. Hornibrook and G. H. Scott also examined the samples (Sheet Fossil Numbers S111/530–543; F 11290, F 11670–76) for microfaunas and reported that the upper 14 samples (to a depth of 320 ft) with the exception of F 11676 (from a depth of 250-260 ft) contained no faunas, and that the remainder indicated an age of from Wanganui Series to Recent. Mr Scott (pers. comm.) states that "The first clear evidence for marine shallow water to littoral conditions is the fauna found in sample F 11675 from a depth of 320–330 ft."

DISCUSSION

The Pliocene-Pleistocene boundary has been placed by Fleming (1953) and Couper and McQueen (1954) between the Waitotaran and Nukumaruan stages of the New Zealand sequence.

The pollen and spore evidence indicates that the Waitotaran-Nukumaruan boundary is probably at a depth of about 310–320 ft in the drillholes (300–310 ft below sea level), and that the boundary between marine and non-marine sediments is at least 100 ft higher. The nature of the sediments, and the presence of fossil shells, pollen, and spores of Waitotaran-Nukumaruan age, show that the fossiliferous sediments form part of the Cannington Gravels; it is probable that all the beds beneath the basalt and tuff belong to this formation. Although no age determinations were obtained, the extremely weathered nature of the gravels immediately underlying the tuff suggests that they, also, are to be correlated with the Cannington Gravels. The only other recorded discovery of marine fossils in the Cannington Gravels in South Canterbury is that by Mr J. D. Raeside in 1946 at Makikihi, reported on by Collins (1953).

The gravel containing the fossils is unweathered, a marked contrast to the usually extremely weathered nature of the Cannington Gravels in exposures. It seems probable that the gravel in the drillhole has not been above the water table since it was deposited.

Whereas formerly the Moa bones immediately beneath the basalt (Forbes, 1890) suggested an approximate lower limit to the age of the basalt (say not older than Pliocene), the fossils from this drillhole enable a lower age limit, probably Lower Nukumaruan, to be assigned to the Moa bones.

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APPENDIX

HYDRAULICS OF THE WELL

The following notes were compiled from the drillers' logs and from conversations with the drillers.

Water was first struck at a depth of 53–58 ft after penetrating the basalt, and rose to within 4 ft 6 in. of the ground surface. This static water level fluctuated from 4 ft 6 in. to 10 ft 6 in. diurnally when the hole was at a depth of 62 ft, and this variation was probably due to tidal effects. As drilling continued the water level dropped until, at a depth of 129–134 ft where a bed of "heaving sand" was penetrated, the water rose to a depth of 43 ft below ground level. The water level then dropped again until, at a depth of 209–211½ ft where a bed of "fine brown sand" was penetrated, it rose to within 66 ft of ground level. Below 211½ ft no measurements of static water level are available until at a depth of 413–416 ft, where from the bed of the fossiliferous gravel the water was artesian with a static water level of 9 in. above the ground surface (3 in. below the top of the casing). This water level varied daily from ground level to 9 in. above ground level. From this depth to the bottom of the hole at 500 ft there was no change in the artesian head.

The drill-hole was pump-tested from aquifers at depths of 58–71 ft, 129–134 ft, and 413–416 ft. These were the only beds that could possibly be regarded as suitable aquifers. The results of these tests are tabulated below. A Berkely Turbine pump was used for all tests.

Position of Aquifer in Feet Below Ground Surface	Lithology	Yield in Gal Per Hour	Duration of Test in Hours	Comments
58–71	Weathered greywacke gravel, clay and sand	4000	10½	Five foot Johnson 30 slot screen used. Base of screen at 71 ft. Pump impellers set at 53 ft.
129–134	"Heaving sand"	350	5	Five foot Johnson 15 slot screen used. Pump impellers set at 97 ft.
413–416	Sandy unweathered greywacke beach gravel	2500, at 3000 a little sand came in	9	Five foot Johnson 15 slot screen used. Pump impellers set at 97 ft. Bailer test gave 2000 g.p.h. with a 30 ft draw-down.

The well was drilled in the hope of obtaining water of a quality suitable for use in locomotive boilers. Although the chloride content of the water diminished appreciably with depth (see table below), at the greatest depth tested it was still regarded by the Government Analyst as unsuitable for use in locomotive boilers.

Depth From Ground Surface (ft)	Chloride Content (p.p.m.)
58– 71	180
129–134	102
413–416	55

The only complete analysis was made of water from a depth of 413–416 ft and is given below.

pH	8·0
A. Nitrate nitrogen	parts per million
	0·1
Nitrate nitrogen	Nil
Ammoniacal nitrogen	0·030
Albuminoid nitrogen	Trace
Oxygen absorbed, 4h, 80°F	0·15
B. *Alkalinity, phth.	–
*Alkalinity, me. or. (carbonate hardness)	135
*Hardness, total (EDTA)	90
*Hardness due to calcium	50
*Hardness due to magnesium	40
Free carbon dioxide	Nil
C. Total dissolved solids	270
Total suspended solids	–
Chloride (Cl)	55
Sulphate (SO4)	–
Iron, total (Fe)	0·4
Iron in solution (Fe)	0·4
Silica in solution (SiO2)	20
*As calcium carbonate	
Smell	Faint oily
Appearance	Clear and bright

Bacteriological Analysis

Plate count at 37°C	Under 5
Coliform organisms MPN/100 ml	Nil

The Government Analyst reports: "The water is good quality for potable use. It is slightly hard and is high in chloride. For locomotives, if this water were used exclusively, trouble could be expected from scaling. If, however, this is only one of a series of waters which locomotives will use the diluting effect of the other waters will probably be sufficient to make this an acceptable supply."

ORDOVICIAN GRAPTOLITES OF NORTH-WEST NELSON: RECENT DISCOVERIES IN THE AORANGI MINE AREA

By S. K. SKWARKO, Victoria University of Wellington.*

(Received for publication, 11 October 1960)

Summary

A short note brings the history of research on New Zealand graptolites up to date. Fourteen fossiliferous collections from the Aorangi Mine area are briefly discussed. Of these, two (GS 7485 and 7493) belong to the Lancefieldian subzone La 2a, not hitherto recorded from North-west Nelson, and characterised by the presence of *Dictyonema pulchellum* T. S. Hall. One other assemblage (GS 7483) contains four-branched *Tetragraptus fruticosus* J. Hall, associated with three branched *T fruticosus,* and belongs to the Upper Bendigonian (Be 3), a Victorian zone not known previously in New Zealand.

In the systematic descriptions, *Dictyonema pulchellum* T. S. Hall (first record in New Zealand), *T. whitelawi* (first record from North-west Nelson), *Didymograptus* cf. *asperus* Harris and Thomas (first record from New Zealand), *Trigonograptus* cf. *ensiformis* (Hall) (first record from New Zealand), and *Isograptus forcipiformis* Rue, var. *harrisi* n. var. are described in detail.

INTRODUCTION AND ACKNOWLEDGMENT

Like graptolite collections obtained from Preservation Inlet two years ago, those collected in February 1959 in the Aorangi Mine area were made in the course of the New Zealand Geological Survey's 4-mile mapping programme. Messrs G. Grindley, B. L. Wood, and A. Wodzicki, geologists of the New Zealand Geological Survey, and also Messrs G. Gibson and M. Hall, senior geology students from Victoria University of Wellington, assisted the author in the collecting of the assemblages as well as in their transport to the New Zealand Geological Survey in Lower Hutt. The opportunity is taken to express most sincere thanks for their assistance.

HISTORICAL

Graptolite-bearing Ordovician slates occupy an area of a few square miles to the south-west of the Whanganui Inlet (previously known as West Haven or West Wanganui Inlet) in the northern extremity of the South Island. These slates at one time contained a fair quantity of gold, and the area, usually referred to as the Aorangi Mine area, was a site of intensive goldmining in the early stages of New Zealand history. Thus, it is not surprising that graptolites were known to occur here as long ago as the third quarter of last century. From that time until 1936, which marked the end of the original graptolite research in New Zealand, many

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well known geologists both local, e.g., Hutton, Hector, Cox, Park, Marshall, Macpherson, and overseas, e.g., Hall, Elles, and others, were directly connected with New Zealand research in graptolites. Finally, in Benson and Keble's masterly treatment of the subject (1935, 1936), all then known Ordovician fossiliferous areas were considered, new collections were described and old ones redetermined in the light of more advanced knowledge of graptolites and their successions.

Since 1936, few contributions on New Zealand lower Paleozoic fossils, stratigraphy and paleogeography, have been published, apart from summaries of such developments in overseas research (e.g., Benson 1938, 1942), as were thought to be of local interest. Allan's essay on the evidence provided by graptolites in determining Pacific Datum Planes (1953) has been the only original contribution to appear in the past twenty years.

In 1958, Skwarko briefly described some stratigraphical and paleontological discoveries in the graptolite-bearing region of Preservation Inlet. The same author (Skwarko, 1960) has summarised his research on newly collected graptolite faunas from the Mount Arthur region of North-west Nelson.

This paper emphasises that work done in the past has certainly not been exhaustive, and that much worthwhile information is still to come from further study of the Ordovician strata of New Zealand.

GRAPTOLITE COLLECTIONS: CONTENT AND AGE

Fourteen collections from the area will be considered, catalogued as GS 7481 to GS 7494.

They vary in age from the lower part of the Middle Lancefieldian zone La 2a to uppermost Castlemainian, Ca 3, of the Victorian sequence.

They are listed in order of decreasing age:

GS 7485 and 7493: La 2a on paleontological evidence.
GS 7484: A small collection, points to Middle Lancefieldian but stratigraphical data indicate almost certainly the lower part of Middle Lancefieldian.

The following are dated purely on paleontological grounds:

GS 7486: Probably Middle Lancefieldian.
GS 7482: Upper part of Middle Lancefieldian (La 2b).
GS 7483: Upper Bendigonian (Be 3).
GS 7488 and 7490: Middle Castlemainian (Ca 2).
GS 7487, 7489, 7491–2, and 7494: Upper Castlemainian (Ca 3).

The age of GS 7481 is not certain but is probably Castlemainian.

The significance of the above datings in increasing our knowledge of the New Zealand Ordovician varies considerably.

Little is added to what is already known by collection GS 7481, a loose boulder of indefinite age picked up in the vicinity of Golden Ridge Mine; GS 7484, a collection in a stream at the mouth of Anthill Mine; and GS 7486, 40 yd downstream from the same mine. Other collections (GS 7487, equivalent to Benson's locality M; GS 7488, close to Benson's locality H; GS 7489, 1 ch up the Jimmy's Ck.; GS 7490, 2 ch upstream from No. 3 Adit of the Aorangi Mine; GS 7491, 8 ch up Little Slaty Ck. from the Aorangi Mine Battery; GS 7492, at the Morning Star Mine; and GS 7494, at the junction of little Slaty Ck. and Anthill Stream), were made primarily to supplement the Geological Survey's graptolite collections, but are also useful confirmation of the previous dating of the strata they come from. In addition, they include the first reported occurrences of several graptolites: a few specimens of *Tetragraptus whitelawi* T. S. Hall, in GS 7487; one specimen of *Trigonograptus* aff. *ensiformis* (T. S. Hall) in GS7492; and an indefinite form resembling *Trigonograptus* from GS 7494. These are described below.

On the other hand, three collections indicate zones not previously recognised. Collections GS 7485 and 7493 represent the zone La 2a, not hitherto determined from the Aorangi Mine area, and GS 7483 represents the Victorian Upper Bendigonian zone, Be 3, not hitherto recognised at all in the New Zealand Ordovician sequence. These three collections make a valuable contribution to the knowledge of New Zealand Ordovician sequences and consequently deserve closer consideration.

The only other collection which has not been mentioned above is GS 7482, from a boulder picked up from Little Slaty Creek, 300 yd above Aorangi Mine Battery. Its age is La 2b, and it provides evidence that Lancefieldian strata extend further south than shown on Benson and Keble's map (1936, map opposite p. 358).

Lower Lancefieldian Subzone La 2a

Locality GS 7493

Boulder at junction of Anthill Stream and Little Slaty Creek. South-west of Whanganui Inlet, Pakawau Survey District, North-west Nelson. Collected by S. K. Skwarko, 15 February 1959. Age—La 2a.

Dictyonema pulchellum T. S. Hall.	Large fragments.
Adelograptus cf. *antiquus* (T. S. Hall).	2
Byrograptus cf. *hunnebergensis* Moberg.	3
Tetragraptus cf. *decipiens* T. S. Hall.	1

Locality GS 7485

In creek bed, 30 yd downstream from the Anthill Mine Adit. Anthill Stream is a tributary of Little Slaty Creek, south-west of the Whanganui Inlet, Pakawau Survey District, North-west Nelson. Collected by G. Gibson, 17 February 1959. Age—La 2a.

Dictyonema pulchellum T. S. Hall.	Small fragments.
Adelograptus cf. *antiquus* (T. S. Hall).	1
Byrograptus cf. *hunnebergensis* Moberg	1
Juvenile *Adelograpti* and *Byrograpti*.	

The loose boulder, one of many examined in Anthill Creek, yielded medium-sized fragments of *D. pulchellum.* Although *D. pulchellum* was not well preserved, its significance was realised in the field, so the source of the boulder was sought and found in the upper reaches of the Anthill Stream, where one of the collections made by Mr G. Gibson (GS 7485 above) yielded quite small, but undoubted fragments of *D. pulchellum.* Although the other graptolites associated with this Dendroid are few, poorly preserved, and often represented by juveniles, they all point to Lancefieldian age. The finer dating of both assemblages is undoubted, since *D. pulchellum* has long been considered one of the key fossils of the Victorian subzone, La 2a, to which it is confined.

This is the first record of the occurrence of *D. pulchellum* in New Zealand, and the first report of the La 2a subzone from the Aorangi Mine area. This horizon has been described by Benson and Keble (1935, pp. 247-8) from the Cape Providence section (localities 1–3) where it is represented by an assemblage consisting of *Dictyonema macgillivrayi* T. S. Hall, *Clonograptus* cf. *magnificus* Pritchard, *Adelograptus* (?) *antiquus* (T. S. Hall), *A.* (?) *antiquus* var. *inusitatus* (Benson and Keble), *A. clarkei* (T. S. Hall), *A.* cf. *lapworthi* (Ruedemann), *A. victoriae* (T. S. Hall), *Bryograptus hunnebergensis* Moberg, *Tetragraptus decipiens* T. S. Hall, *T. decipiens* var. *bipatens* Harris and Keble and *Didymograptus taylori* T. S. Hall, together with several species of Phyllocarids.

UPPER BENDIGONIAN ZONE Be 3

Locality GS 7483

10 ft inside Aorangi Mine No. 3 Adit, south-west of Whanganui Inlet, Pakawau Survey District, North-west Nelson. Collected by S. K. Skwarko, 17 February 1959. Age—Be 3.

Clonograptus cf. rigidus (J. Hall)	1
Goniograptus cf. *thureaui* (McCoy)	4
Tetragraptus fruticosus 3-br (J. Hall)	3
Tetragraptus fruticosus 4-br (J. Hall)	2
Tetragraptus fruticosus juveniles	6
Tetragraptus cf. *serra* (Brongn.)	3
Tetragraptus decipiens T. S. Hall	1
Phyllograptus anna J. Hall	5
Didymagraptus cf. *asperus* Harris and Thomas	7
Didymograptus cf. missilis J. Hall	1
Dichograptid fragments	10

In Victoria the Bendigonian stage has been divided into four zones numbered Be 1–Be4, in upward succession. This subdivision is based upon the appearance, evolution, and finally, the disappearance of *Tetragraptus fruticosus* (J. Hall). Its first appearance in the graptolite-bearing strata marks the beginning of the Bendigonian stage, and in zone Be 1, the basal Bendigonian, it is associated with *T. approximatus* Nicholson, persisting from the Upper Lancefieldian zone La 3. In zone Be 2, *T. fruticosus* alone is present. The incoming of its three-branched mutation marks the commencement of the zone Be 3. This zone persists until all the four-stiped forms die out, and finally, in the highest Bendigonian zone, Be 4, only three-branched forms are found. Thus the association of the four- and the three-branched *T. fruticosus* is characteristic of the zone Be 3.

The collection of graptolites from GS 7483 includes three specimens of *T. fruticosus* 3-br, two adult specimens of *T. fruticosus* 4-br, and six juvenile forms of the latter species. Other graptolites present have been taken into consideration and the assemblage has been dated as Upper Bendigonian Be 3. This is the first record of this zone in New Zealand.

SYSTEMATIC DESCRIPTIONS

Class GRAPTOLITHINA

Order DENDROIDEA

Family DENDROGRAPTIDAE Roemer in Frech, 1897

Genus Dictyonema Hall, 1851

Dictyonema pulchellum T. S. Hall (Fig. 1)

1899 *Dictyonema pulchellum* Hall, Proc. Roy. Soc. Vict. 11 pt 2: 174, pl. 18, fig. 27.

Diagnosis

Stipes set closely together so that their width is either slightly greater than that of the interspaces or occasionally equals them. Dissepiments thinner than the stipes, expanding at their bases and unevenly spaced, producing sub-squarish, oval, or semi-rectangular meshes.

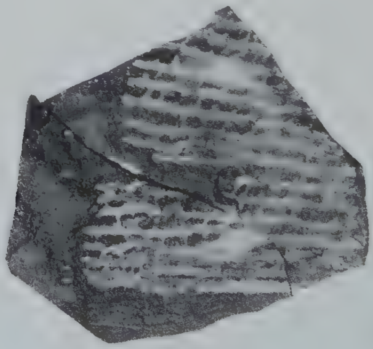

FIG. 1—*Dictyonema pulchellum* T. S. Hall. GS 7493. Middle Lancefieldian La 2a. *Photo by G. Bell, Dept. of Mines, Melbourne, Victoria.* × 1.

Description

The apical portion of the rhabdosome has provided the original description of this species; Hall's description of this Victorian specimen was as follows:

> "Hydrosome circular, about 15 mm in diameter; branching dichotomously from the base, at fairly regular intervals. Radial branches about 1 mm apart and about 0·2 mm broad, expanding at the point of junction with the radial branches. Thecae with slightly concave apertural margin at right angles to the branch; outer margin straight, forming an angle of 25–30 degrees with the axis of the branch; probably about 7 in 10 mm."

No young forms comparable to the original Victorian material have been found in New Zealand. Description of the mature fragments is as follows:

Stipes four to five in 10 mm, about 0·8 mm wide (0·75–0·9 mm) and spaced at 1·5–2 mm intervals. The dissepiments which connect them are 0·4 mm wide in the middle but expand to 0·75 mm at their bases to produce semirectangular, oval, or squarish meshes. Dissepiments average 6–7 in 10 mm, but their spacing is not constant. Thecae have not been observed.

Remarks

In Victoria where it was first described, *D. pulchellum* is one of the characteristic fossils of the Lancefieldian subzone La 2a. Since the establishment of this species many mature specimens have been found; as far as is known, however, no description of a mature *D. pulchellum* has so far appeared in Australian literature.

Occurrence and Age

Two collections, GS 7493 and GS 7485, both of lower subzone of Middle Lancefieldian, provided specimens (entirely fragmentary) of *Dictyonema pulchellum*. *D. pulchellum* occurs commonly in Victoria in strata of the same age.

Order GRAPTOLOIDEA

Family DICHOGRAPTIDAE Lapworth, 1873

Pauciramous forms

Section TETRAGRAPTI

Genus Tetragraptus Salter, 1863

Tetragraptus whitelawi T. S. Hall (Fig. 2)

1914	*Tetragraptus*	*whitelawi*	Hall, Proc. Roy. Soc. Vict. 27 pt 1: 114–8, pl. 17, fig. 16.
1935	,,	,,	Benson and Keble, Trans. Roy. Soc. N.Z. 65: 279, pl 30, fig. 234.
1939	,,	,,	Keble and Benson, Nat. Mus. Melbourne, Mem. 11: 88.

Description

Sicula not observed. Primary branches arising at 180°, straight or considerably flexed but uniformly 0·4mm in width, and each from 4 to 6 mm in length, branching by dichotomy at their extremes. Secondary branches disposed at 90° or less to each other, 0·5 mm thick and up to 20 mm long, often flexed inwards. Thecae 6–8 in 10 mm, inclined at 10°–12° to stipe, with an overlap not exceeding one-third. Free ventral edge slightly concave, apertural margins concave and normal to the thecal axes. Bitheca or budding individuals not observed.

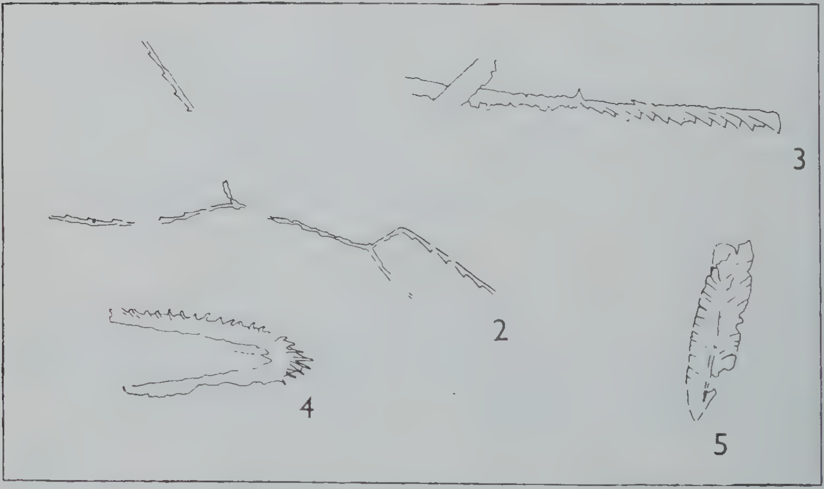

Fig. 2—*Tetragraptus whitelawi* T. S. Hall. GS 7487. Upper Castlemainian Ca 3. × 2.

Fig. 3—*Didymograptus* cf. *asperus* H. & T. GS 7483. Upper Bendigonian Be 3. × 2.

Fig. 4—*Isograptus forcipiformis* Rue. var. *harrisi* var. nov. GS 7494. Upper Castlemainian Ca 3. × 2.

Fig. 5—*Trigonograptus* cf. *ensiformis* (J. Hall). GS 7492. Upper Castlemainian Ca 3. × 2.

Remarks

The Aorangi Mine specimens bear close resemblance to the Victorian types. Small differences lie in the closer thecal spacing of the Victorian type (10 in 10 mm), and in the somewhat higher angle of inclination of its thecae (15°).

New Zealand Occurrences and Age

Benson and Keble (1935, 279) identified fourteen specimens of *T. whitelawi* from four Fiordland localities ranging in age from Be 4 to Ch 2.

During the recent survey five specimens were obtained from the locality GS 7487 of Upper Castlemainian age.

Overseas Occurrences and Age

In Victoria *T. whitelawi* occurs in strata ranging from Uppermost Bendigonian to Middle Castlemainian. As far as is known this species has not been recorded from any other part of the world.

Associates

Dichograptus octobrachiatus, Tetragraptus serra, Didymograptus extensus, D. extensus-nitidus trans., *Isograptus caduceus* var. *lunata, I. caduceus* var. *victoriae, I. hastatus.*

Section DIDYMOGRAPTI

Genus ***Didymograptus*** M'Coy in Sedgwick and M'Coy, 1851

Didymograptus cf. ***asperus*** Harris and Thomas (Fig. 3)

1938 *Didymograptus asperus* Harris and Thomas, Mining and Geol. J. 1 (2): 76–7, pl. 2, figs. 25a–c; pl. 4, fig. 23.

Description

Sicula triangular, about 1 mm. long. Stipes given off at 180°, but the angle of divergence first increases after the first four or five thecae, and then decreases, giving a gently convex appearance to the stipes. Branches up to 5 cm long, increasing rapidly from an initial thickness of 0·6 mm close to the sicula to a maximum observed value of 1·5 mm distally. Thecae 11–12 in 10 mm, their ventral margins distinctly concave. Overlap one-half to one-third.

Remarks

New Zealand specimens differ from the Victorian types in the somewhat denser spacing of the thecae and their slightly lower angle of inclination. This, and the rather poor preservation of the material, prevents a definite identification.

New Zealand Occurrences and Age

The seven specimens examined were obtained from locality GS 7483 of Upper Bendigonian age. This is the first record of this species in New Zealand.

Overseas Occurrences and Age

Australia (Victoria): Lower and Middle Bendigonian (Be 1–3).

Associates

For associated forms see fossil list for GS 7483 above.

Family ISOGRAPTIDAE Harris, 1933

Genus *Isograptus* Moberg, 1892

Isograptus forcipiformis (Ruedemann) *harrisi* n. var. (Fig. 4)

Description

Rhabdosome 14 mm long. Sicula less than 2 mm long. Thecae 7–8 in 10 mm. The branches are widest (2 mm) close to the sicula, narrowing at first rapidly to 1·2 mm, then gradually to 1·0 mm at the distal extremity of the branches. Otherwise similar to the North American types.

Remarks

The new variety differs from the type in the shorter sicula and in the greater attenuation and somewhat different shape of the branches.

Occurrences and Age

Six specimens examined were obtained from locality GS 7494 of Upper Castlemainian (Ca 3) age.

Associates

Didymograptus cf. *nitidus, D.* cf. *extensus, Isograptus caduceus* var. *divergens, I. caduceus* var. *maximo-divergens, I. caduceus* var. *victoriae,* (?) *Trigonograptus* sp. The new variety is named in honour of the Australian paleontologist W. J. Harris whose work greatly contributed to knowledge and understanding of *Isograpti.*

Family ?DIPLOGRAPTIDAE INCERTAE SEDIS

Genus **Trigonograptus** Nicholson, 1869

Trigonograptus cf. ***ensiformis*** (J. Hall) (Fig. 5)

1865 *Retiolites ensiformis* J. Hall, Geol. Surv. Canada dec. 2: 114 pl. 14, figs. 1–5.

1908 *Trigonograptus ensiformis* Elles and Wood, Mon. Brit. Grapt. pt. 7: 302 pl. 35, figs 1 a–c.

1939 ,, ,, Keble and Benson, Nat. Mus. Melbourne, Mem. 11: 88.

Description

Rhabdosome suboval in outline. Its incomplete length is 13 mm. Its breadth of 3 mm is attained rather rapidly. Thecae in the form of long tubes about 4 times as long as wide, some apparently straight, others curved, inclined at 50°–70° to the longitudinal axis of the rhabdosome, numbering 17 in 10 mm, usually in contact throughout its length.

Remarks

The single specimen in the collection is incomplete, lacking both proximal and distal extremities. The sicular end, however, is almost complete and the increase in its breadth has been at least as rapid as in *T. ensiformis.* The stated high density of thecae is not certain owing to poor preservation.

One row of thecae has a constant inclination of about 60°, but occasionally a slight curvature in thecal outline can be discerned. The inclination of the thecae in the other row is only 50°, but one tube has been observed to be strongly curved so that its proximal part is inclined at about 45° and the distal at 70°. In overall shape the specimen is suboval, so that its original length can be closely estimated as not exceeding 15 mm.

The specimen is closer to *T. ensiformis* than to any other *Trigonograptus* so far described, but the resemblance between the two is not perfect. However, its preservation is too poor to allow definite conclusions so that the comparison with *T. ensiformis* is made provisionally, until better material is available.

New Zealand Occurrences and Age

The specimen was obtained from locality GS 7492 of Upper Castlemainian (Ca 3) age. In 1936 Benson and Keble (p. 373) noted ". . . some obscure forms resembling *Trigonograptus ensiformis* J. Hall." from GS 1231 of the Mount Arthur area. Because of their poor preservation they were neither figured nor described so that this seems to be the first definite record of this genus from New Zealand.

Overseas Occurrences and Age

T. ensiformis occurs in North America in bed 6 (Zone with *Diplograptus dentatus*) of the Deepkill section, and also at other localities. In England it occurs in Arenig, Upper Skiddaw Slates (Ellergill) beds, the homotaxial equivalent of North American zone of *Diplograptus dentatus.*

In Australia *T. ensiformis* is a common form in the Yapeenian and Darriwilian, but it makes it first appearance in the Upper Castlemainian beds below. Its appearance in New Zealand in the Upper Castlemainian strata is, therefore, in accordance with its overseas stratigraphical position.

Associates

Isograptus caduceus var. *maximo-divergens* and *I. caduceus* var. *victoriae.*

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